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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

COMPUTER SIMULATED DEVELOPMENT
OF
A COMMAND TO LINE-OF-SIGHT MISSILE
USING ON-OFF CONTROL

by

Je Young, Yeun
December 1983

Thesis Advisor: H. A. Titus
Co-advisor: Alex Gerba, Jr.

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An on-off control provides a minimum time response for missile control. For application in missile control systems, it is wasteful of control effort (due to chatter) to use a ideal relay. Hence it is necessary to modify the ideal relay into a saturating linear control. The result was almost the same to that of using the ideal relay.

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Computer Simulated Development of a Command to Line-of-Sight Missile Using ON-OFF Control

by

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Submitted in partial fulfillment of the
requirements for the degree of

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An on-off control provides a minimum time response for missile control. For application in missile control systems, it is wasteful of control effort (due to chatter) to use a ideal relay. Hence it is necessary to modify the ideal relay into a saturating linear control. The result was almost the same to that of using the ideal relay.

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I. INTRODUCTION

Guided missiles are classified into four broad categories, depending on launch and target position characteristics. These categories are (1). air -to - air (2). air - to - ground (3). surface - to - air and (4). surface -to - surface. Each category of the above will employ one or more of the following guidance schemes; programmed command, line-of-sight, lead-angle, proportional navigation homing and inertial. The beam rider guidance is included in the line-of-sight guidance. A number of missiles also use a combination of these methods. For example, the initial part of the missile trajectory may use programmed guidance while the terminal phase may use beam-rider.

This thesis discusses the surface-to-air missile controlled by on-off, thrust vector, control. Consideration was given to determine the effects of the two-level relay and the saturation linear control. In order to verify the results, it was tested by using the type of control for three different types of missile-target scenarios:

(1). LOS command against non-maneuvering target

(2). LOS command against maneuvering target

(3). Pseudo-LOS command against non-maneuvering target.

In chapter 2, a discussion of a line-of-sight guidance was presented and a practical example of it was shown in chapter 3. The general concept of on-off control was described in chapter 4. The simulation results of the basic command to line-of-sight against both a non-maneuvering and a maneuvering target were shown in chapters 5 and that of pseudo-LOS case was in chapter 6. Finally, a discussion of two-level relay and saturating linear control was presented in chapter 7. A table of variables which were used in this

thesis is shown in the Appendix A. Computer simulation was accomplished using Digital Simulation Language, DSL.

II. OVERVIEW OF LINE-OF-SIGHT GUIDANCE CONTROL

A LOS system can be called a "3-point" guidance system since there is one point which defines the tracker, another the target and a third which defines the position of the missile. The object of the guidance system is to constrain the missile to lie as nearly as possible on the line joining the tracker and the target called the Line Of Sight (LOS). The concept is simple and can be implemented in many ways; perhaps it is this apparent simplicity which explains why many of the guided weapon systems as yet designed are LOS system.

Consider a target flying straight and at constant speed, and a missile flying at a different angle but constant speed, having been launched when the target occupies a position TO (see Figure 2.1).

After intervals of time of 1,2,3 etc seconds the LOS is shown as OT1,OT2,OT3 etc. Since the missile ideally always lies on these lines the flight path will be a curved one, for an approaching target, the curvature becomes increasingly severe towards the end of the engagement. We note that the tangent to the flight path at any one point defines the instantaneous direction of the missile velocity. It is seen that the missile velocity vector will, in general, not be directed along the LOS; towards the end of the engagement it may be at a considerable angle to it [Ref. 1].

In an actual situation the guidance signals transmitted to the missile are the demanded lateral accelerations (LATAX) in two axes at the right angles to the beam. These demands are resolved into missile axes within the missile. An error compensation term endeavouring to keep the error off the beam (σ_{mt}) equal to zero.

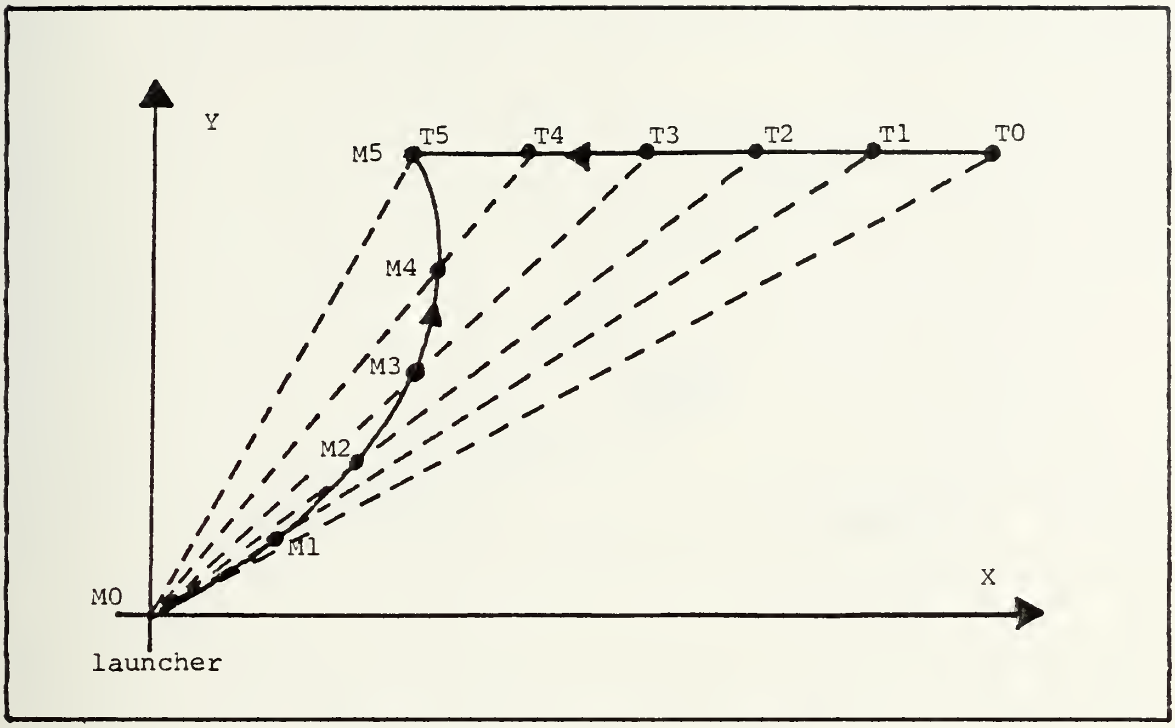


Figure 2.1 Missile Target Encounter with LOS Guidance

A basic geometry and a simplified guidance loop are shown in Figure 2.2 and Figure 2.3.

Suppose that the cross range error (CRE) of Figure 2.2 can be measured either directly or by means of the angular difference between OT and OM, together with some knowledge of missile range (Rm), then

$$\mathrm{CRE} = \mathrm{Rm}(\sigma_t - \sigma_m) \qquad (2.1)$$

If this error off the beam is used as an acceleration demand U, it needs some damping so that good response characteristics are obtained. A dynamic equation of the form

$$\ddot{\mathrm{CRE}} = \mathrm{G1}\ (\dot{\mathrm{CRE}}) + \mathrm{G2}\ (\mathrm{CRE}) \qquad (2.2)$$

needs to be satisfied, where G1 and G2 are constants. This necessity leads immediately to the consideration of a filtered error. In the presence of noise on the sight-line,

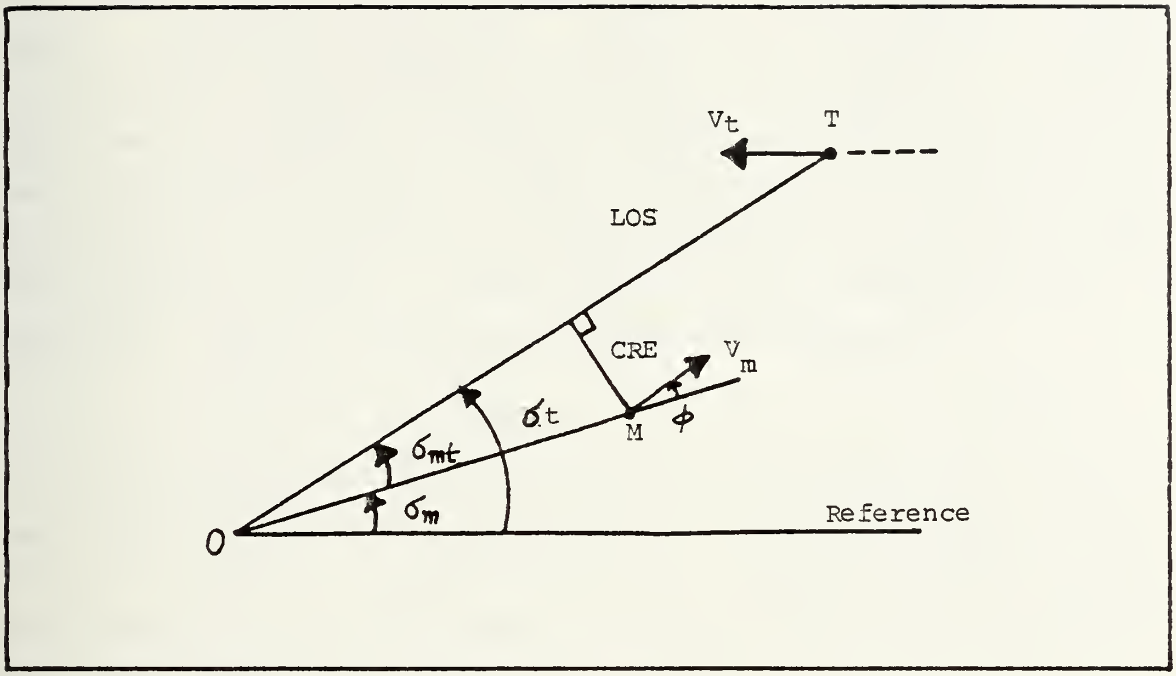


Figure 2.2 Basic Geometry

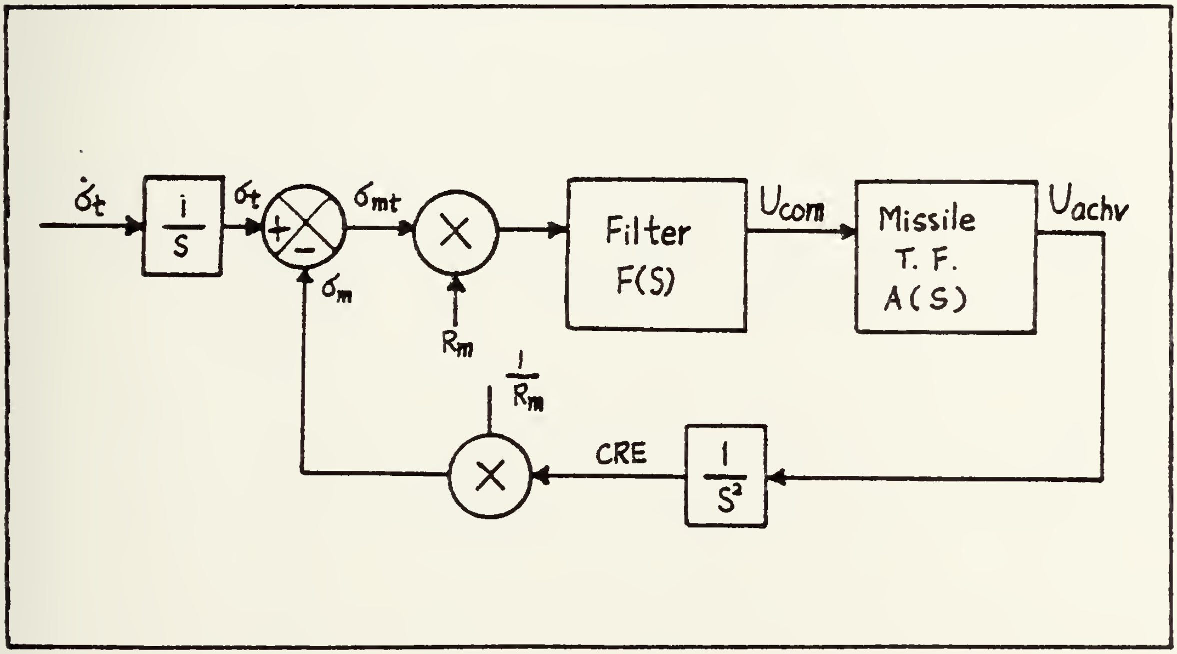


Figure 2.3 Simplified Guidance Loop of LOS Guidance

and hence on the cross range error, CRE, such a filter design is not simple and becomes a compromise between requirements for smoothing the noise and giving an adequate response to a demand. Modern techniques allow filters to be designed statistically if some knowledge of the noise characteristics is available or can be assumed. Figure 2.3 shows the position of such a filter F(s) in the guidance loop. It includes a gain G, and the acceleration demand is

$$U = F(s)\ Rm\ (\sigma_t - \sigma_m) \qquad (2.3)$$

The missile transfer function is represented by A(s) and when the achieved acceleration is doubly integrated and divided by Rm it represents a new measure of the missile beam angle (σ_m), thus closing the loop when differenced with the target beam angle (σ_t).

While this concept is simply a LOS or beam riding guidance situation it is by no means as clear in homing how a guidance law can be devised in the absence of information on missile and target positions [Ref. 2].

III. TYPICAL ENGAGEMENT SEQUENCE

In order to provide a "vehicle" through which to better understand the basic aspects of command to line-of-sight guidance methodology, the engagement sequence of a short-range, air-defense, missile system is described. The Roland system was selected because the general operational aspects of the system are available at the unclassified level [Ref. 4].

The entry of one or more aerial targets into the range of the search radar is indicated to the Roland vehicle commander by an audible tone. At the same time, a synthetic display of the targets appears on a screen to give the commmander all the information needed to select the most threatening target. The screen images are different for friendly and enemy targets. Also, the entry of the target into the missile envelope, utilizing target advanced-range computations, is indicated by a change in the display. With the search antenna raised and the search radar activated, target acquisition is possible even when the vehicle is in motion.

There are three modes of identification, friend or foe (IFF) interrogation: automatic, manual, and automatic within a given range.

When the commander has recognized a target as hostile and decided to engage it, he places a cursor over the screen image. This automatically brings the turret to bear and tracking can commence in either the "radar" or "optical" modes.

In the "radar" mode, the tracking radar automatically accepts target designation from the search radar, searches for, locks onto, and tracks the target.

In the "optical" mode, the aimer searches for the target in elevation with an optical sight. To aid him an electronic instrument displays the maximum theoretical elevation for the search. When the aimer has acquired the target in his cross-hairs, he keeps the target in his sight by manipulating a control stick. This control keeps the target properly positioned by moving the turret in azimuth and swivelling a mirror in elevation.

As soon as the commander confirms that the target is within missile range, he initiates the firing sequence in the "radar" mode, or authorizes "optical" mode firing through a command displayed in the aimer's sight. The aimer, then, can initiate the firing sequence.

The missile is guided by a command to line-of-sight technique. This means that the target is tracked optically or by radar and the deviation of the missile from this line of sight is determined and corrected by a guidance command. The commander may switch from "radar" to "optical" and back again, as desired, even after the missile has been launched.

Target tracking and determination of the missile's deviation from the line of sight are different for each mode. In the "radar" mode, the guidance radar has two receiving channels. One is used for target tracking and the other is used to locate the missile in the radar lobe through reception of the missile's radio frequency beacons. By comparing these angles, an error between the missile and the target line of sight can be determined. In the "optical" mode, a biaxially-stabilized mirror is manually controlled to keep the target vertically in the aimer's sight and the turret is rotated to the azimuth of the target line of sight. An infrared goniometer is mounted to provide misile angle from the tracker by following flares mounted on the rear of the missile. Then, a deviation of the missile angle from the target line of sight can be determined.

Two groups of signals are introduced into the command computer: the velocity of the line of sight in azimuth and elevation, and the deviation of the missile from the line of sight in azimuth and elevation. Based upon data from the line-of-sight movement and the angular deviations of the missile, the necessary guidance signals are calculated.

The guidance signals are relayed to the missile by a transmitter with highly directional characteristics. The command-transmitting antenna is slaved to the missile angle in both azimuth and elevation. It, therefore, is trained on the missile continuously.

The side forces required for missile course corrections are produced through deflection of the exhaust jet of the sustainer motor by spoilers at the rear of the missile (thrust-vector control).

When the missile reaches the point of impact with the target, the warhead is detonated by either percussion, contact fuse or the radio-frequency, proximity fuse. The warhead consists of a radial-effect, multiple-fragmentation charge.

Figure 3.1 presents an operational schematic of the basic Roland missile system operation.

The computer simulations contained herein are generic in nature within the command to line-of-sight guided-missile type and have only reasonable estimates of missile capabilities introduced. This ensures unclassified results. At the same time, the simulations are of sufficient complexity to properly weigh the relative merits of the guidance variations discussed [Ref. 3].

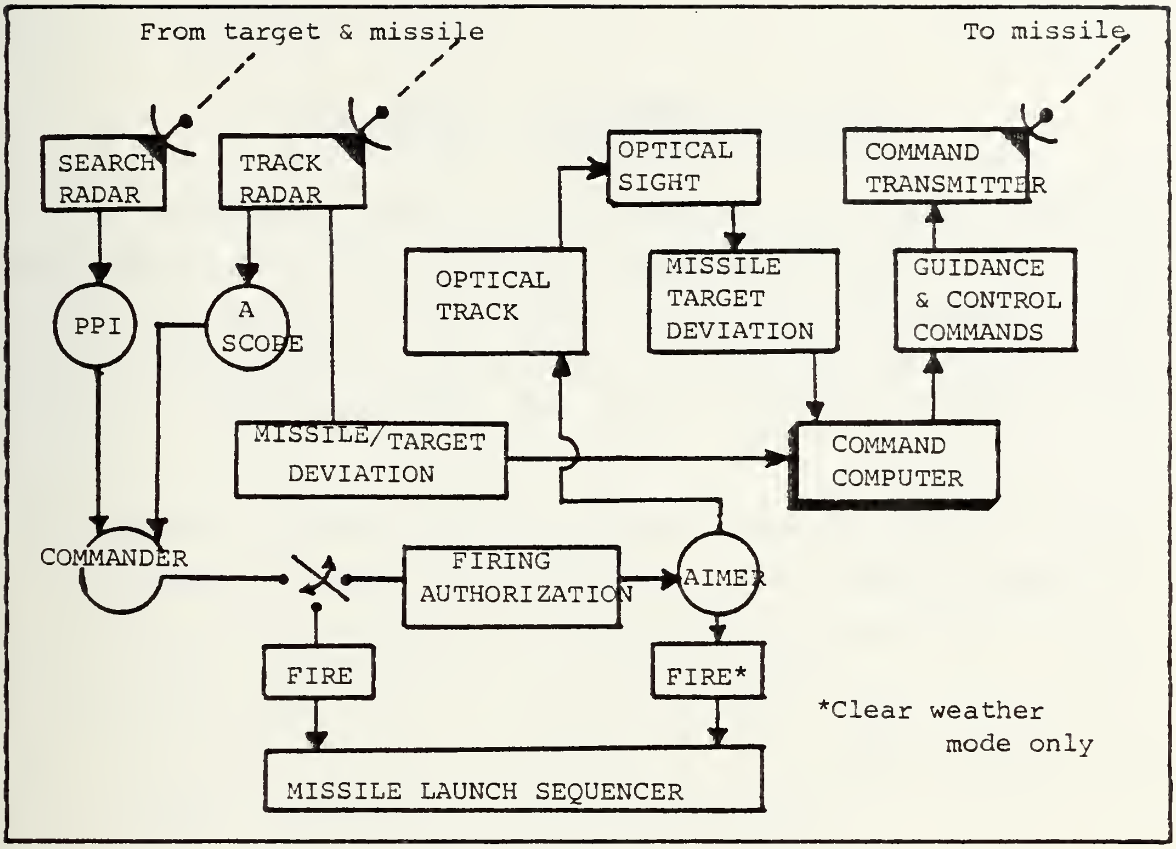


Figure 3.1 Roland Missile System Operational Schematic

IV. ON-OFF (BANG-BANG) CONTROL

As discussed before, LOS guidance maintains a missile position on the LOS. Usually missile position has a cross range error (CRE) and we want to reduce this error to zero in the minimum time. This kind of problem can be solved by using the on-off control. The basic concept of this is that;

> Given a system for which the drive is limited (has a maximum or saturation value), the fastest response is obtained if maximum forward drive is applied at t = 0, and is reversed at a proper instant t = t1 so that deceleration under maximum reverse drive reduces the velocity to zero at precisely the command value of the output. The drive is then set to zero.

The ideal relay permits only two conditions; full acceleration and full deceleration [Ref. 5].

From the Bang-Bang control law, we can derive the switching function which makes the error go to zero by using the proper switching time. From Newton's second law;

$$F = m\,\ddot{\mathrm{CRE}}$$

$$\ddot{\mathrm{CRE}} = \frac{d}{dt}(\dot{\mathrm{CRE}}) = \frac{F}{m} = U$$

$$\dot{\mathrm{CRE}} = \ddot{\mathrm{CRE}}\,dt = U\,t + k1$$

But at t = 0 , $\dot{cre} = 0$ and k1 = 0. Therefore

$$\dot{\mathrm{CRE}} = \frac{d}{dt}(\mathrm{CRE}) = U\,t \qquad (4.1)$$

$$\mathrm{CRE} = \dot{\mathrm{CRE}}\,dt = U\,t^2 + k2 \qquad (4.2)$$

From the equation 4.1

$$t = \dot{CRE} / U$$

$$t^2 = (\dot{CRE} / U)^2 \qquad (4.3)$$

Substitute equation 4.3 into equation 4.2

$$CRE = (U / 2)(\dot{CRE} / U)^2 + k2$$

$$= (\dot{CRE})^2 / (2 U) + k2 \qquad (4.4)$$

where k2 is integration constant. But if we apply a full deceleration at the halfway point, the equation 4.4 becomes

$$F = (\dot{CRE} \, |\dot{CRE}|) / (2 U) + CRE \qquad (4.5)$$

and is called the ERROR FUNCTION. U will be

$$U = \pm G$$

or

$$U = -(G) \, SIGN(F) \qquad (4.6)$$

Equations 4.5 and 4.6 represent the SWITCHING FUNCTION which makes the error go to zero in the minimum time. The switching function and the block diagram of the on-off controller are depicted on the Figures 4.1 and 4.2. And we can obtain the cross range error, CRE, by doubly integrating U with the initial condition of CRE. We have

$$\dot{CRE} = U \, dt + \dot{CRE}(0)$$

$$CRE = \dot{CRE} \, dt + CRE(0) \qquad (4.7)$$

The simulation results of these equations are given on Figures 4.3 through 4.7 and the computer program is attached (see Appendix B).

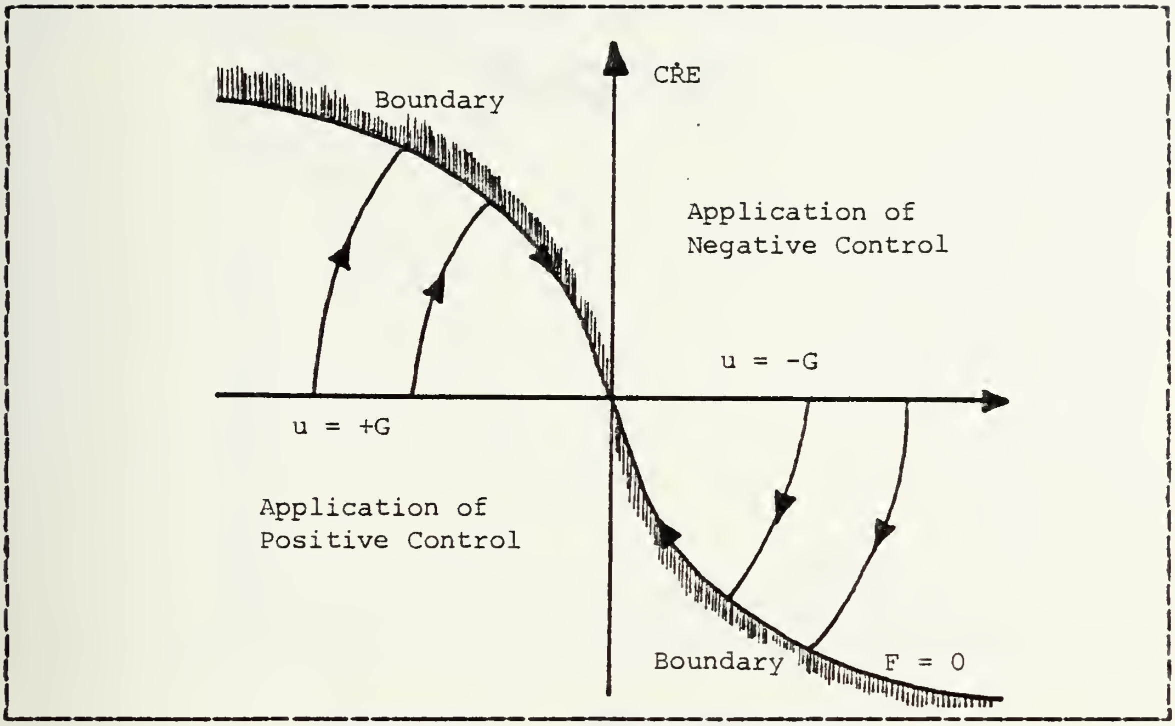


Figure 4.1 Parabolic Switching Function

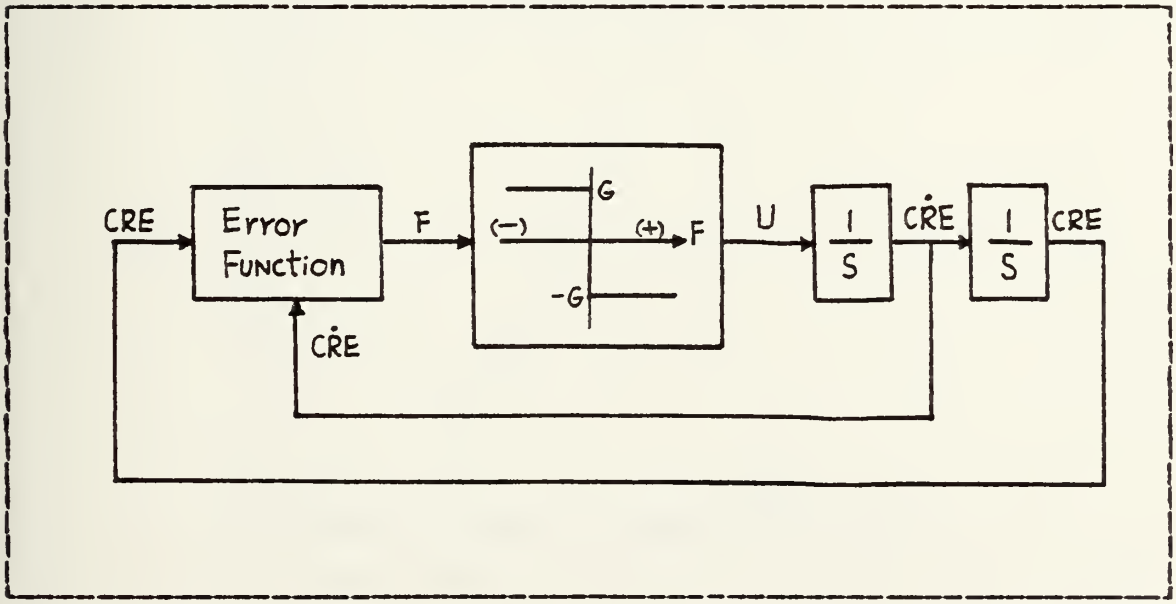


Figure 4.2 Block Diagram of ON-OFF Controller

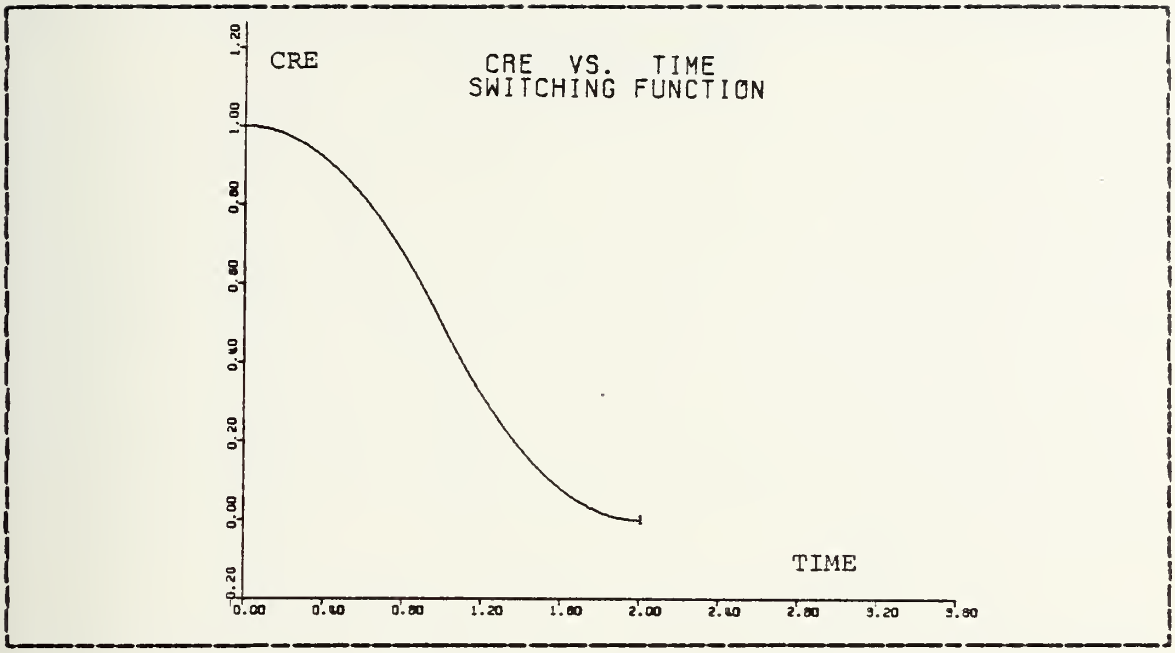


Figure 4.3 CRE versus Time

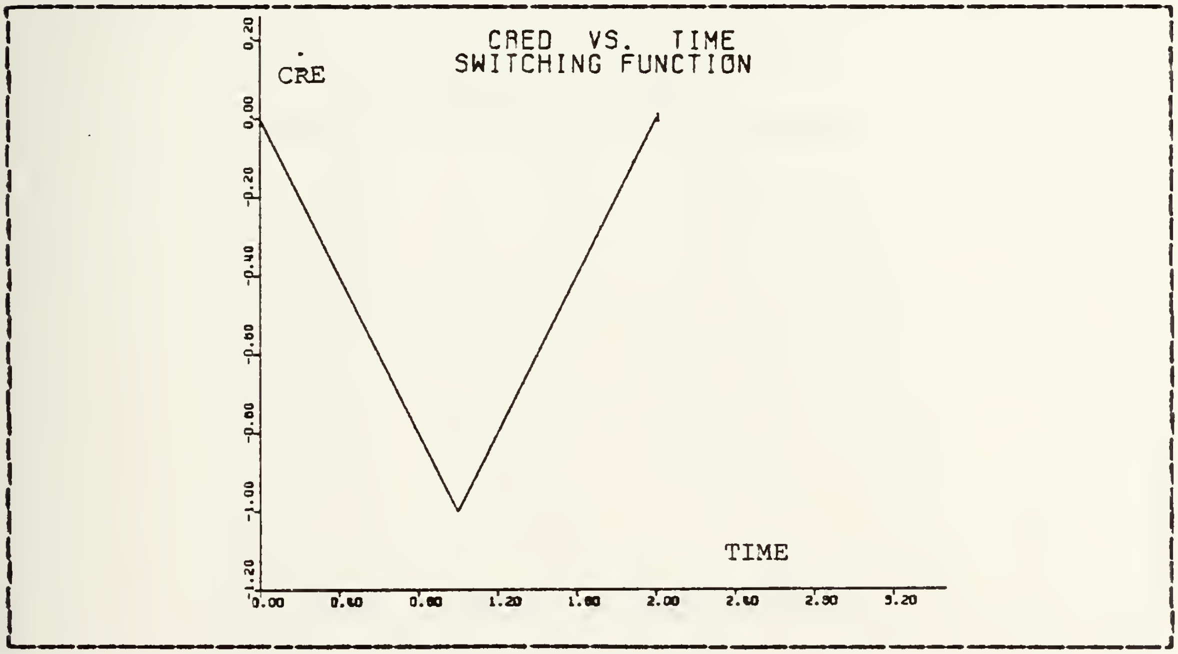


Figure 4.4 C$\dot{R}$E versus Time

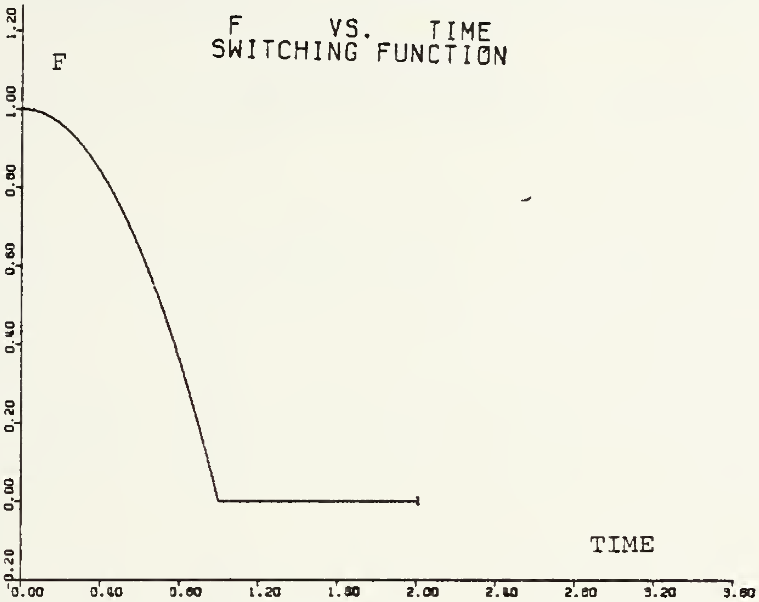


Figure 4.5 F versus Time

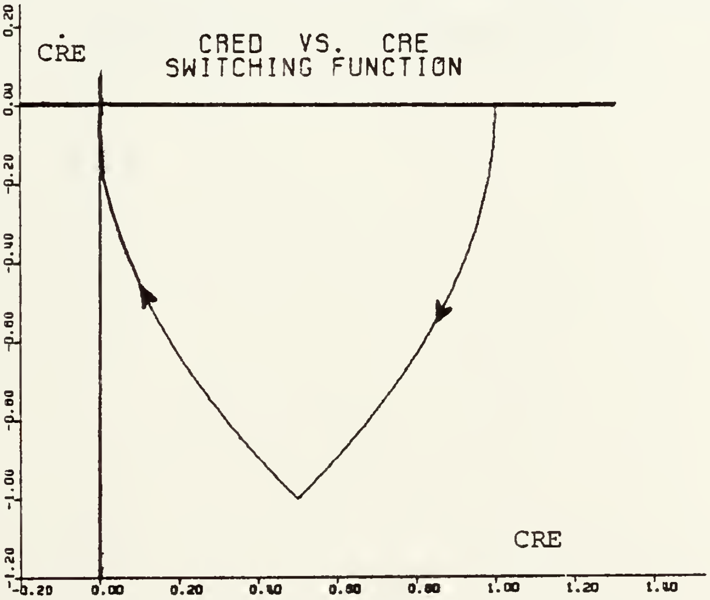


Figure 4.6 $\dot{\mathrm{CRE}}$ versus CRE

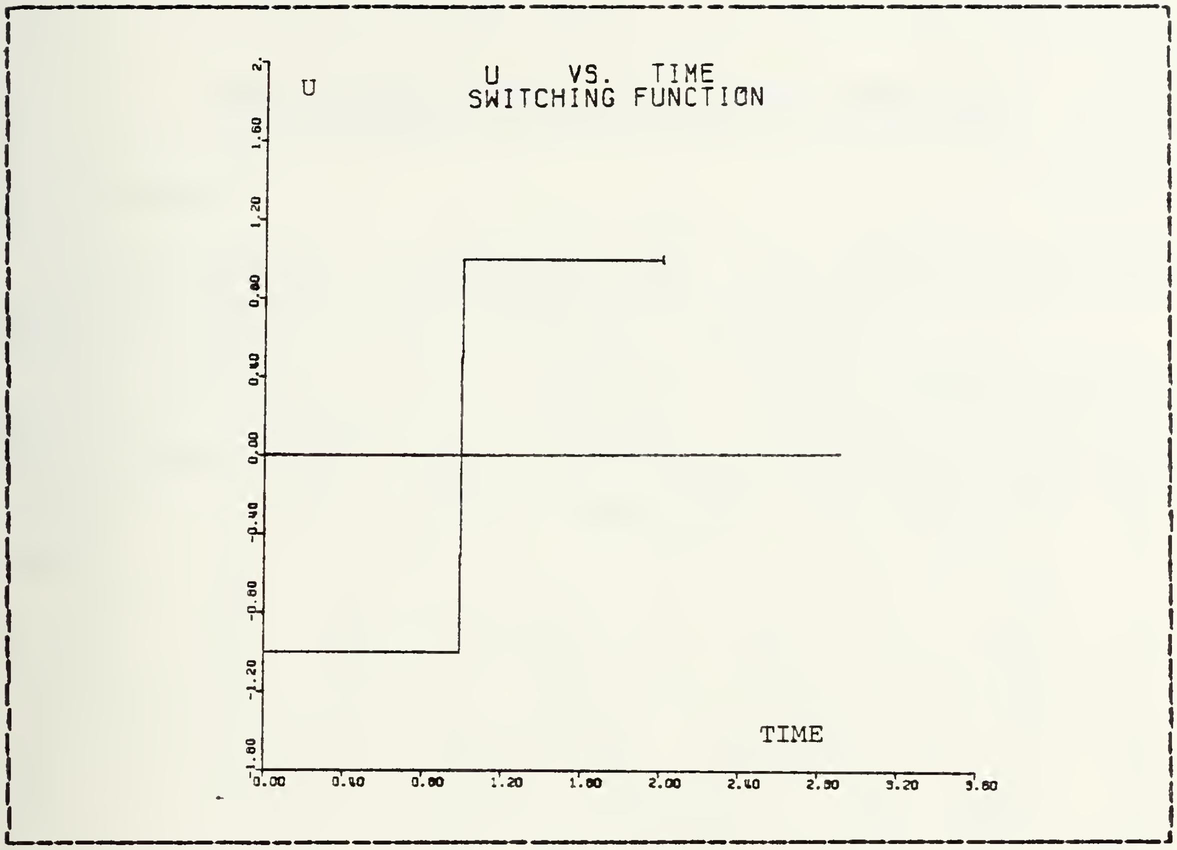


Figure 4.7   U versus Time

V. BASIC COMMAND TO LINE-OF-SIGHT SIMULATION

A. SCENARIO

The engagement was designed with the ground tracker and missile launching unit located at the origin.

The target was flown accross the first quadrant from a position 4000 meters on the x-axis and 1000 meters on the y-axis (4000,1000). The velocity vector of the target was parallel to the x-axis and magnitude was 250 meters per second.

Since most missiles need a few seconds of boost, the missile is not controlled during this time. We assumed that the missile was controlled after one second from the firing time and controlled by PROGRAMMED GUIDANCE up to this time. After the time of missile "capture", the missile was controlled by the on-off, TVC method with the LOS guidance law. The simplified flow chart is shown in the Figure 5.1.

In order to simplify the problem, we assumed that:

1) the velocity vector of missile, Vm, was parallel to the LOS between the target and origin and the magnitude of Vm was constant, 500 meters per second;
2) the LATAX was applied to the missile at right angles to the LOS. This was a reasonable assumption for this kind of missile. So the angle $\phi + \sigma_m$ in the Figure 2.2 is almost same to angle σ_t;
3) the measurement noise was zero so we omitted the filter, F(s);
4) the magnitude of LATAX was 150 meters/second^2 which was about 15 Gs.

The geometry depicted in Figure 5.2 summarizes the geometric situation.

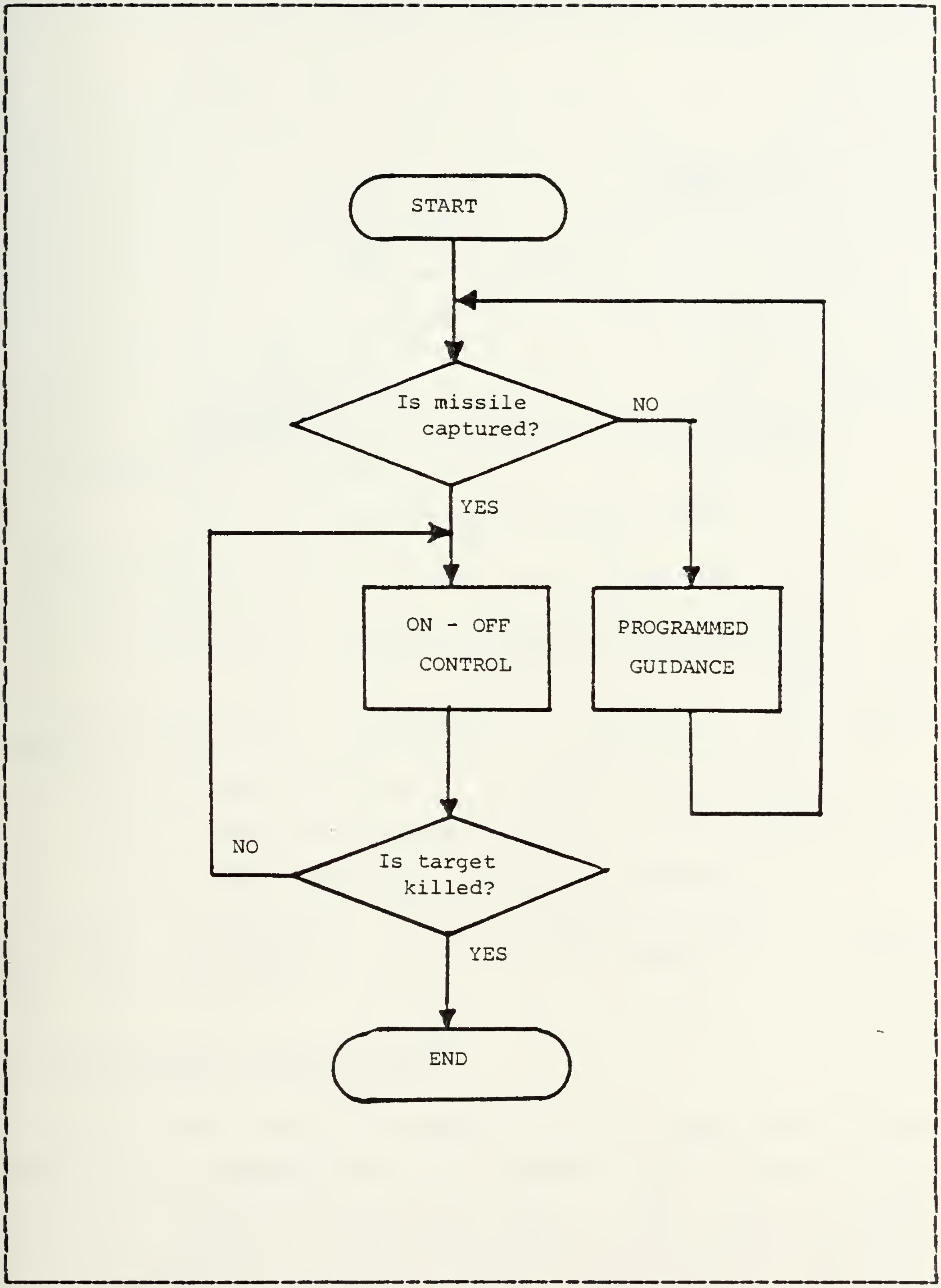


Figure 5.1 Simplified Flow Chart of Basic LOS Command

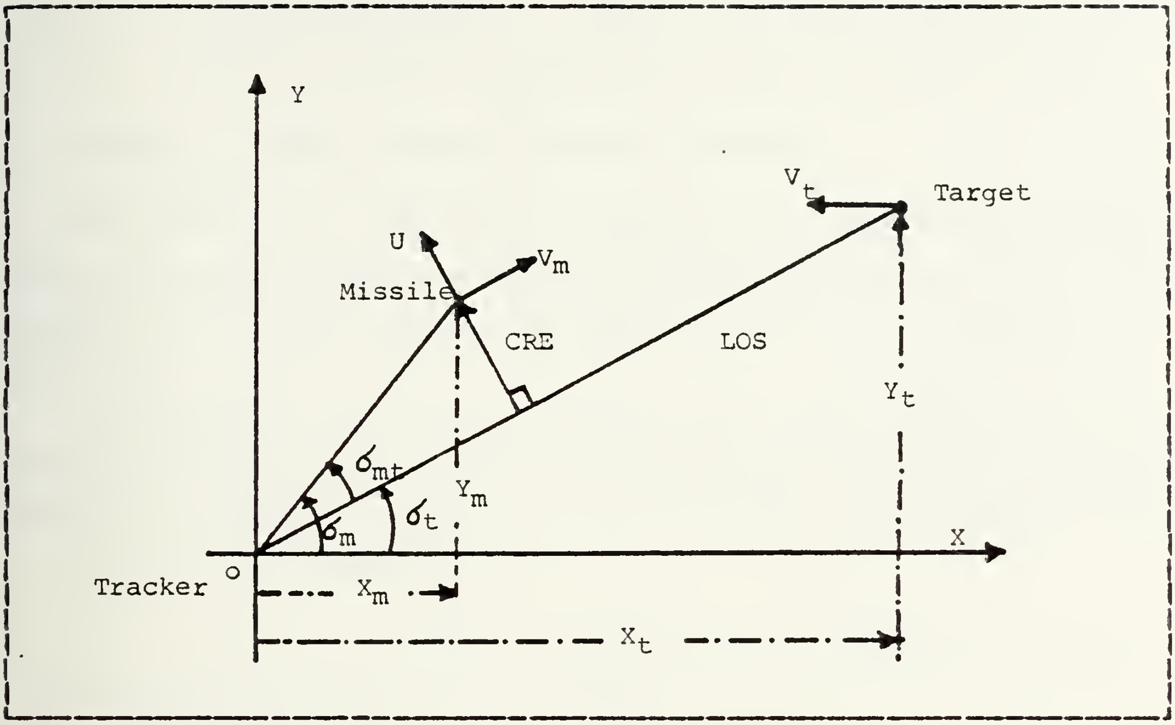


Figure 5.2   Geometry of Basic LOS Guidance

For mathmatical convenience of simulation, we need to define the sign of the CRE and the LATAX as follow;

$+|CRE|$: When the missile position is upper-side of LOS
$-|CRE|$: when the missile position is lower-side of LOS
$+|U|$: when the LATAX is upward direction
$-|U|$: when the LATAX is downward direction

This sign was based on the positive σ_{mt} which is defined when σ_m is greater than σ_t .

B. PROGRAMMED GUIDANCE PHASE

Since the major emphasis of this paper was on-off control, we assumed that the missile flew along the LOS during the programmed guidance phase. But, in a practical situation, there is some cross range error which is occured by disturbances such as wind, propulsion system and

autopilot time delay,etc. Hence we made initialization errors, and the on-off control started with these errors.

C. ON-OFF, THRUST VECTOR, MISSILE CONTROL

The detail of the on-off control was discussed before, hence we applied this to the LOS guidance scheme. The block diagram of this system is depicted in the Figure 5.3 [Ref. 3].

In order to determine the CRE, the tracker estimates the missile's range (Rm), by the elapsed time of flight and the missile's velocity profile. The program of this simulation is attached in Appendix C.

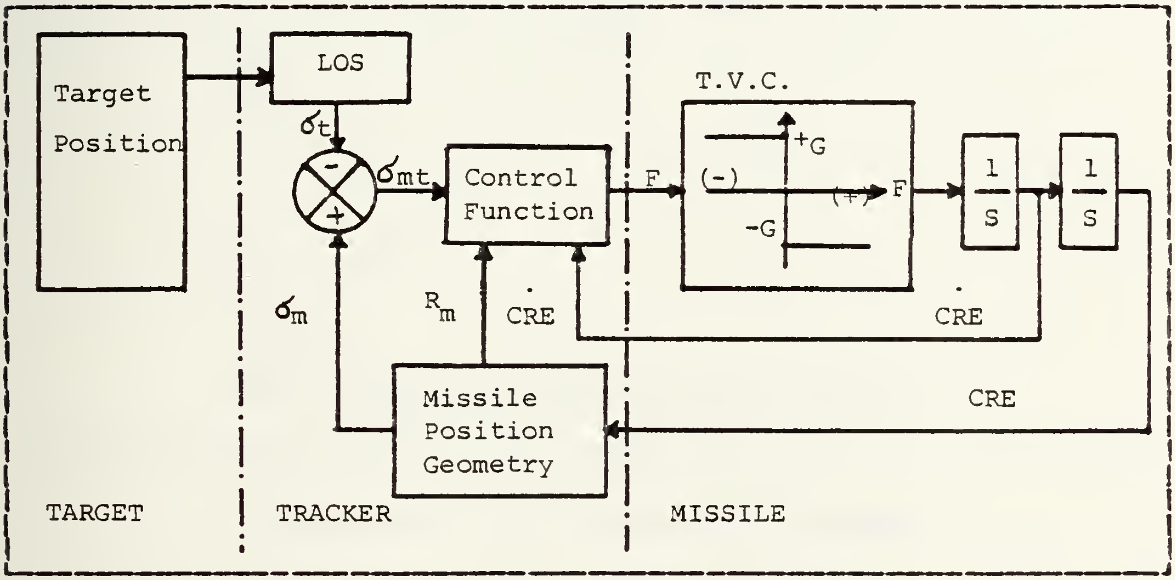


Figure 5.3 Block Diagram of the Basic LOS Command

D. SIMULATION RESULTS

Figure 5.4 shows the missile and target geometry in X-Y plane. The missile intercepted the target at the point A(2605,1000) with the almost zero miss distance.

Figure 5.5(a) shows the distance between target and missile versus time. The distance decreased linearly and neared zero at the time at 5.58 seconds.

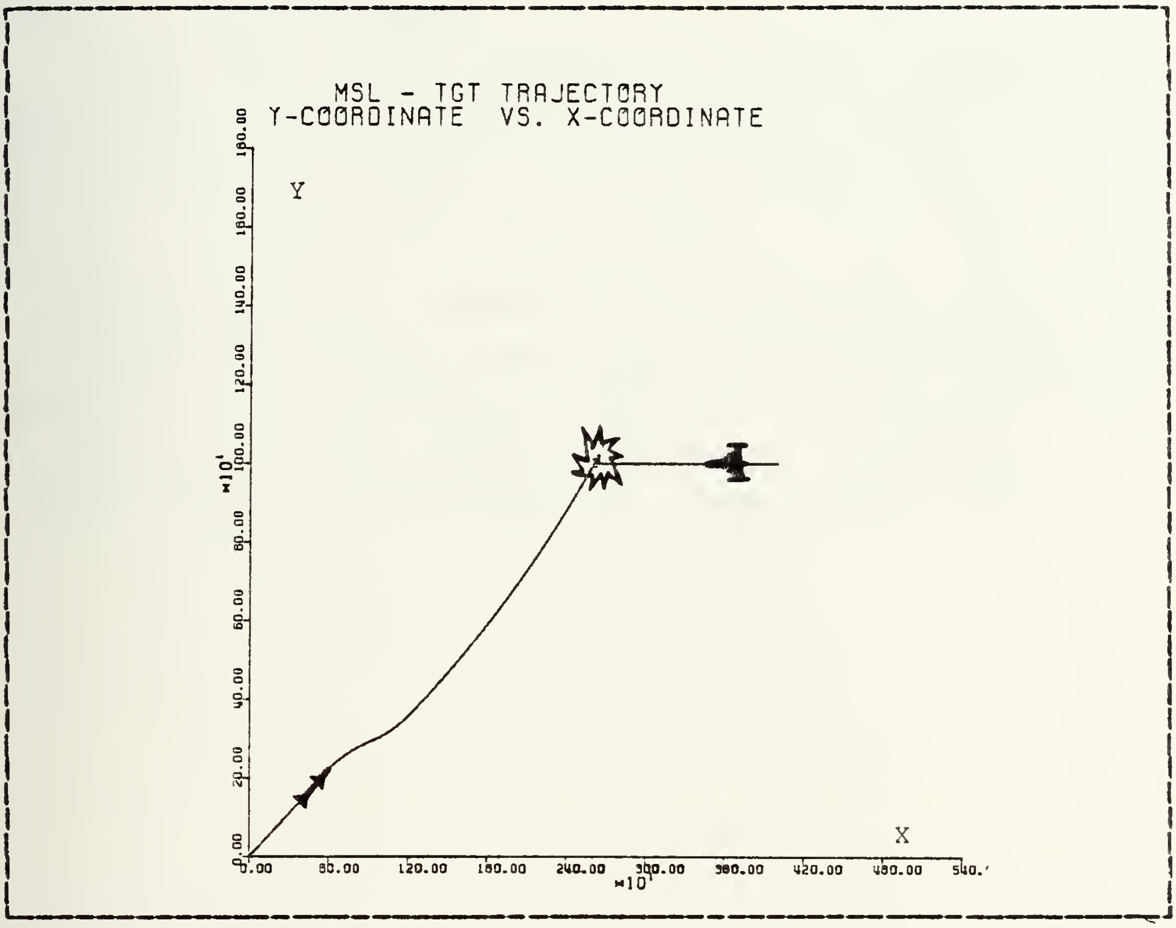


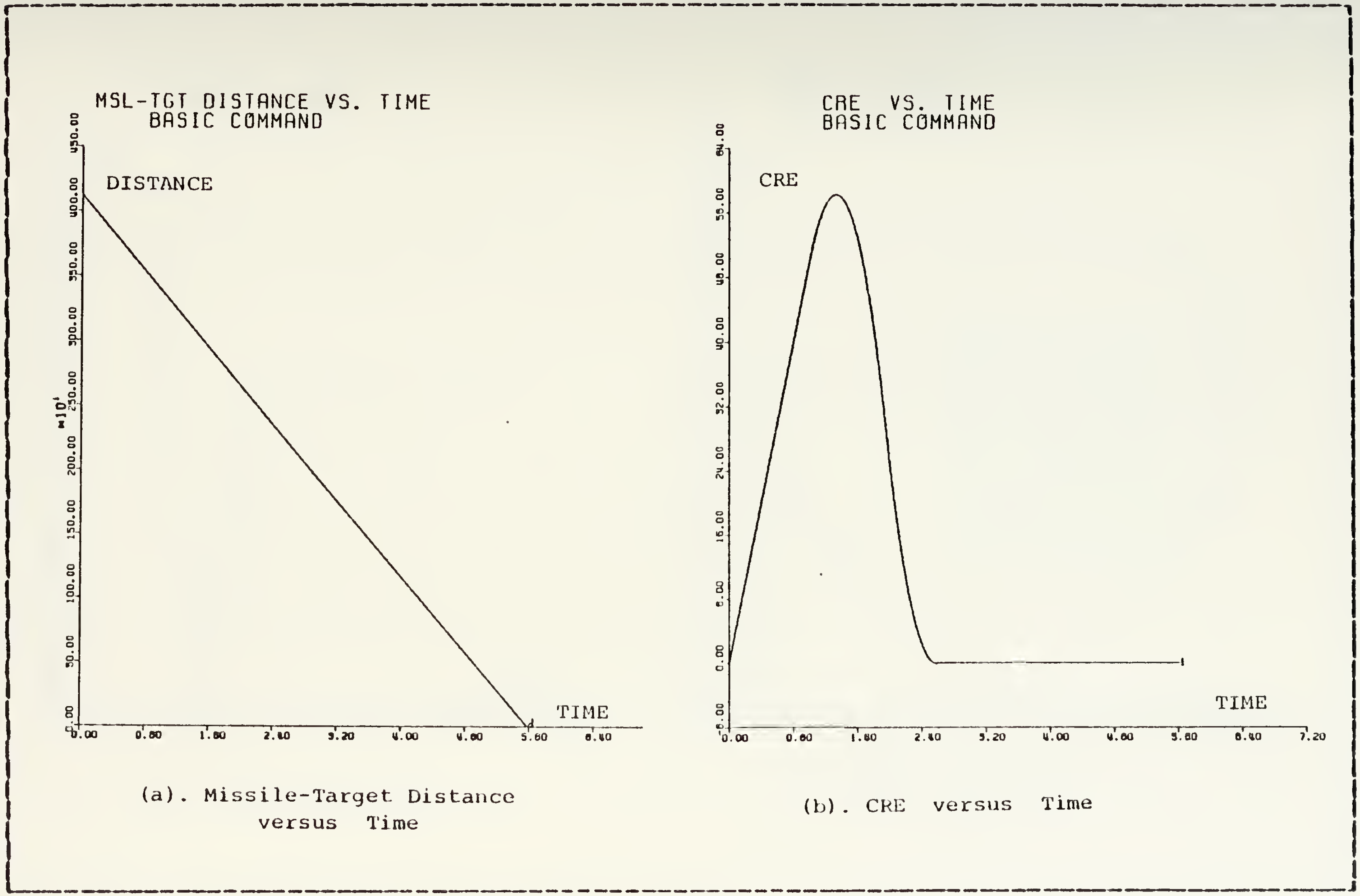
Figure 5.4 The Basic LOS Command

Figure 5.5(b) shows the CRE versus time. The initial cross range error at the missile capture time one second after firing was about 50 meters. Since the $\dot{CRE}$ at the "missile capture time" was positive, the CRE increased initially. So the maximum CRE was about 58.2 meters at the time 1.330 seconds. Then it decreased to almost zero meter at 2.55 seconds. To get a faster response, we should increase the magnitude of the LATAX. We should note here

that the CRE does not maintain zero value because we did not consider the target motion terms in this phase of the simulation [Ref. 2]. So the missile had some small cross range error and the BANG-BANG controller had tried to reduce this error in a chatter-mode.

Figure 5.6(a) shows the CRE versus time. Figure 5.6(b) shows the $\dot{CRE}$ versus CRE. As we expected this curve followed the SWITCHING FUNCTION as shown in figure 4.4. Figures 5.7(a) and 5.7(b) show the F versus time and the U versus time.

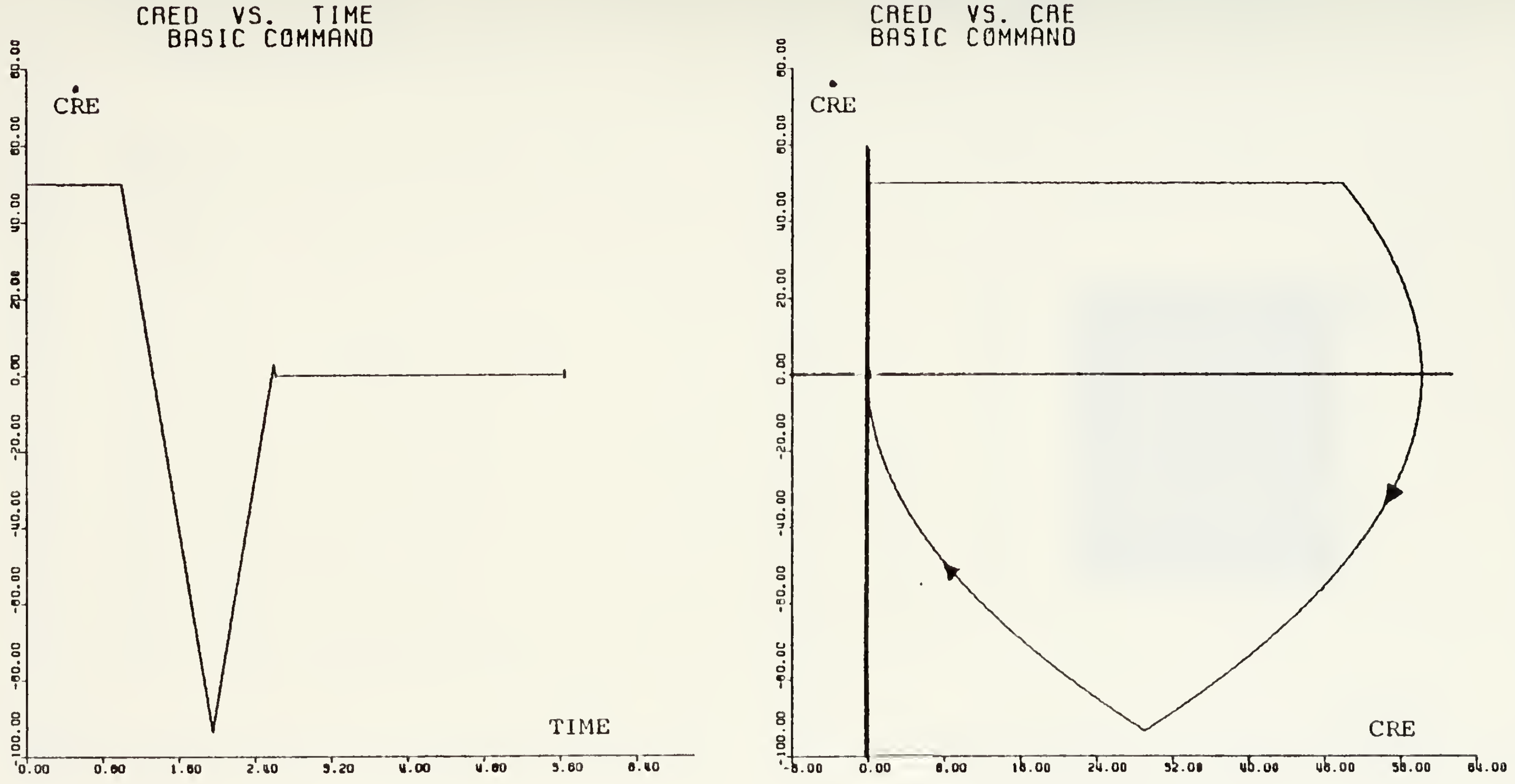
This program was tested using maneuvering targets and the results were almost same except the impact position. The results of this simulation were shown on the Figures 5.8 through 5.11 and the program is attached in Appendix D. The comparison of these simulations is summarized in Table I.



(a). Missile-Target Distance versus Time

(b). CRE versus Time

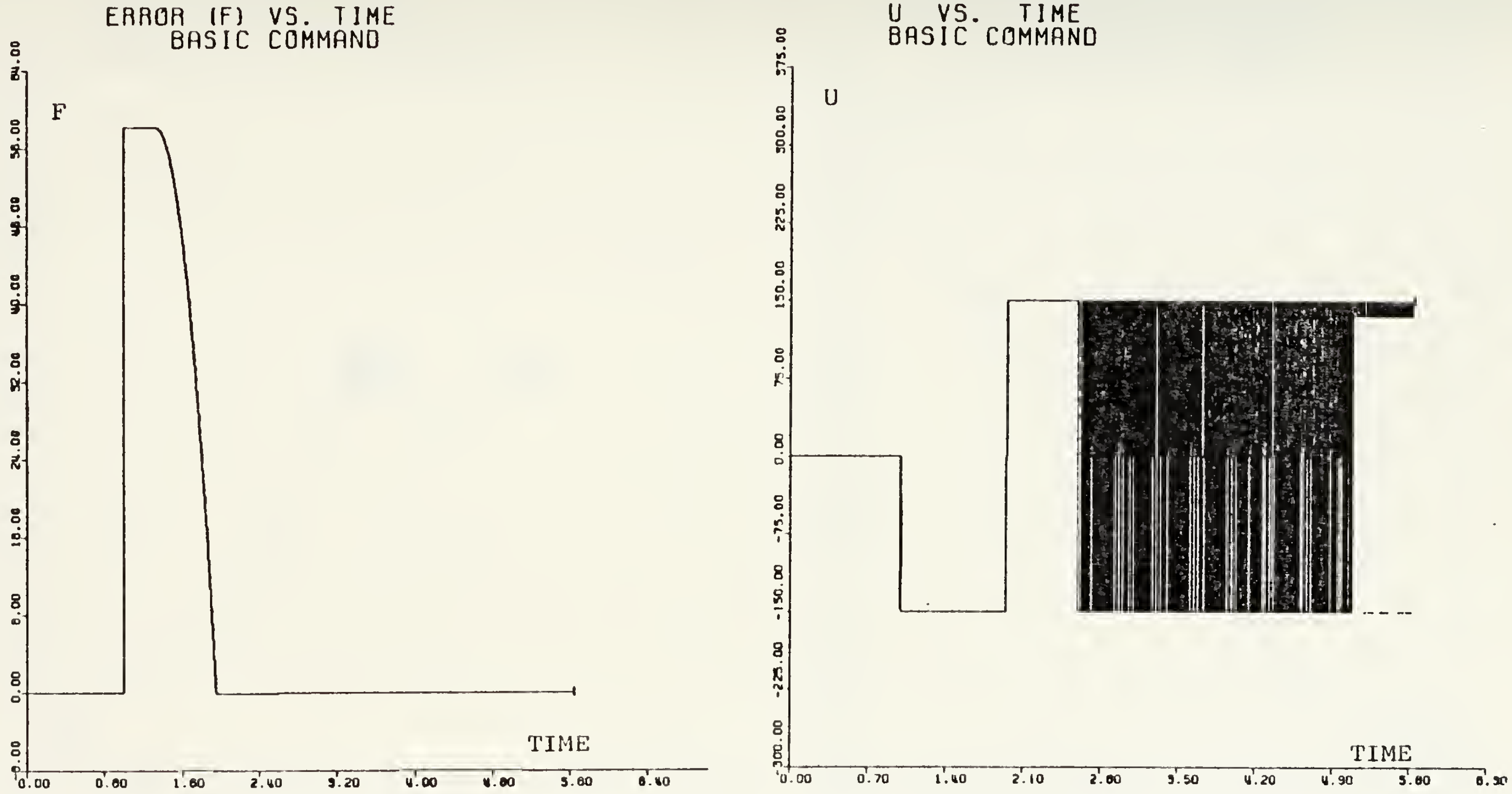
Figure 5.5 The Basic LOS Command



(a). $\dot{\text{CRE}}$ versus Time

(b). $\dot{\text{CRE}}$ versus CRE

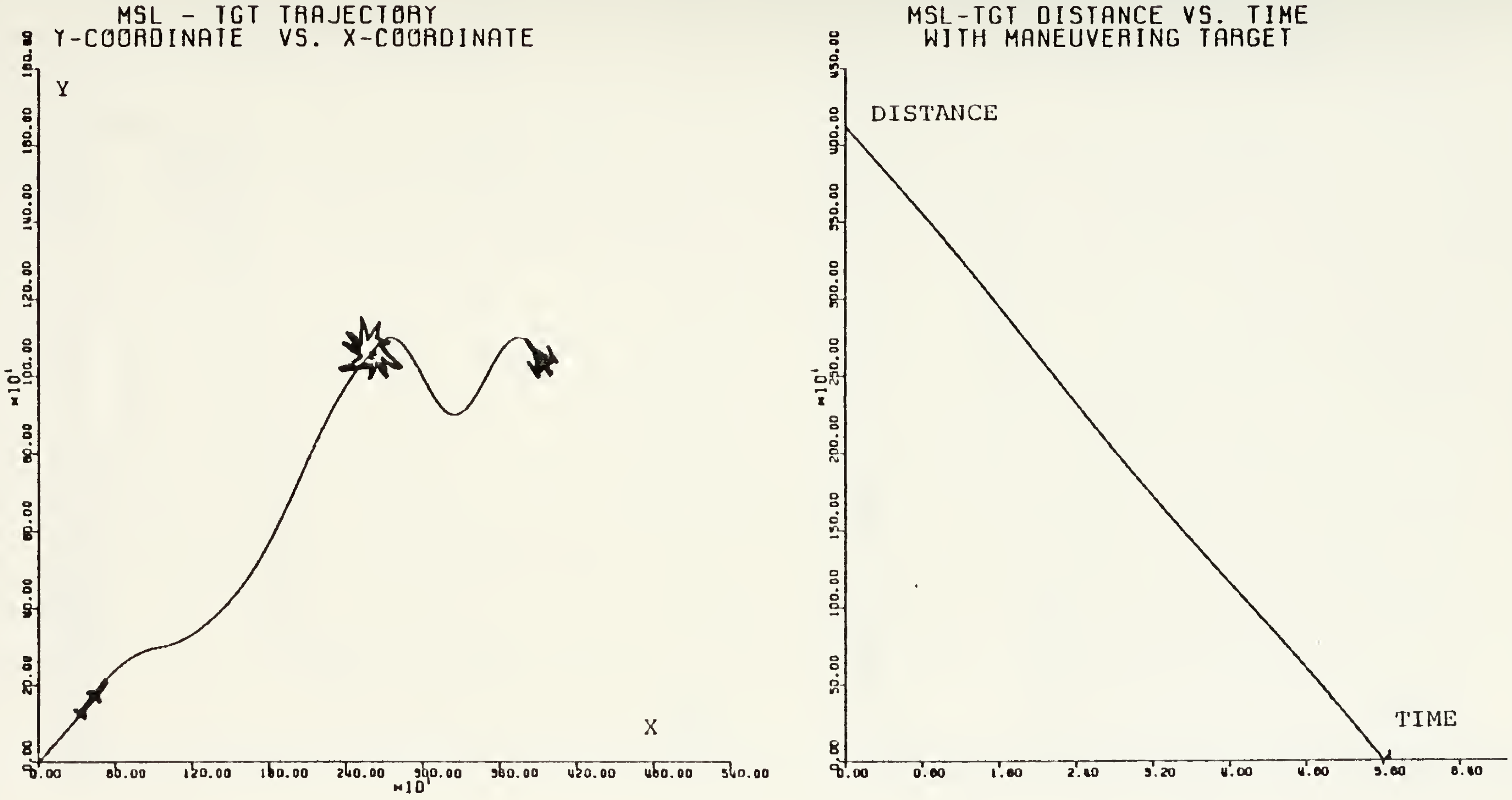
Figure 5.6 The Basic LOS Command



(a). F versus Time

(b). U versus Time

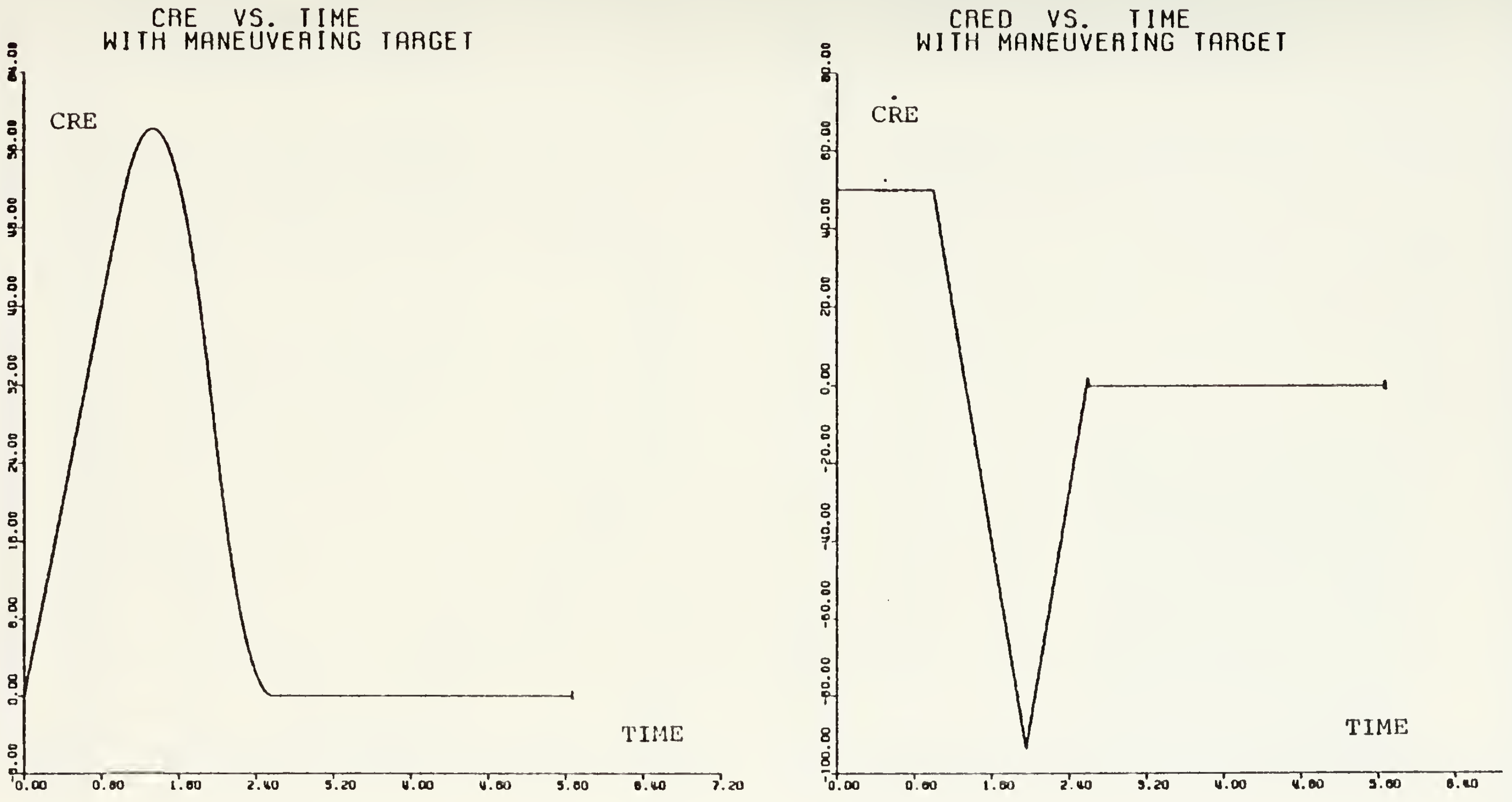
Figure 5.7 The Basic LOS Command



(a) Missile-Target Trajectory

(b). Missile-Target Distance versus Time

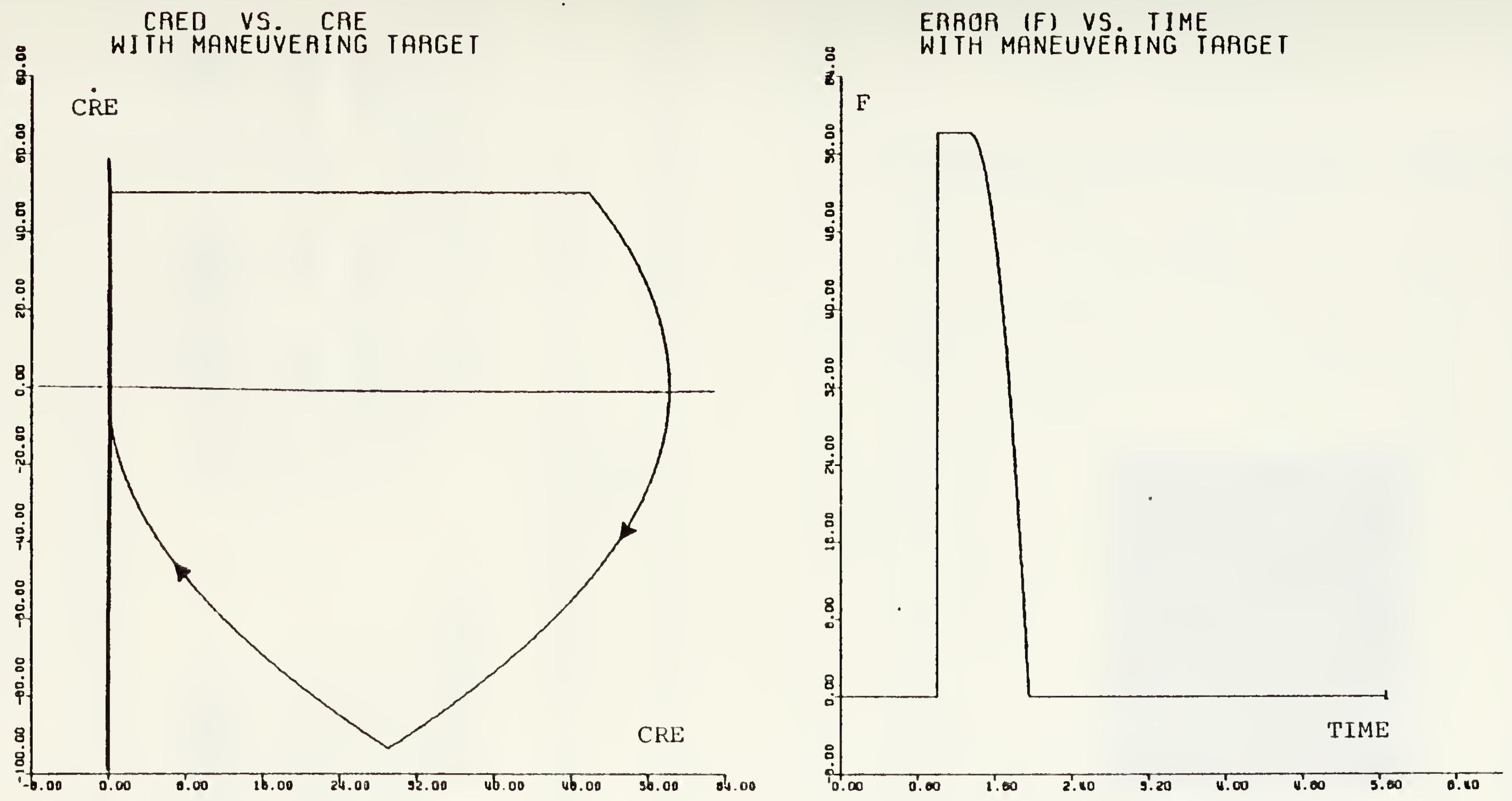
Figure 5.8 The Maneuvering Target



(a). CRE versus Time

(b). $\dot{\mathrm{CRE}}$ versus Time

Figure 5.9 The Maneuvering Target



(a). $\dot{CRE}$ versus CRE

(b). F versus Time

Figure 5.10 The Maneuvering Target

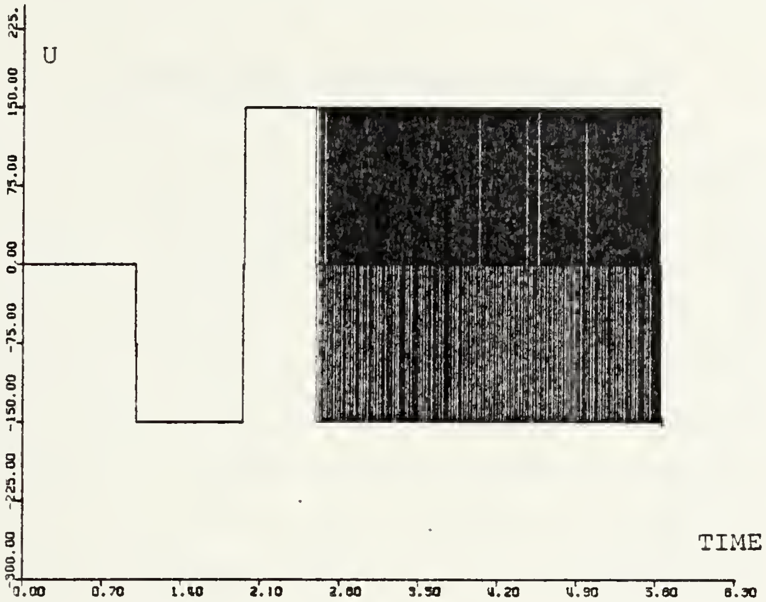


Figure 5.11 U versus Time for a Maneuvering Target

TABLE I

The Basic LOS Command Simulation Result

NON-MANEUVRING TARGET	MANEUVERING TARGET
.time(control) = 1.0 sec	1.0 sec
CRE(0) = 49.910(m)	49.907(m)
CRED(0) = 49.832(m/sec)	49.891(m/sec)
.time(max.CRE) 1.33 sec	1.33(sec)
CRE(max) = 58.184(m)	58.201(m)
.time(intercept) = 5.58 sec	5.61 sec
(Xm,Ym) = (2604.7,999.88)	(2597.9, 1057.7)
CRE = 4.3344 E-5	-6.5448 E-6
distance= 0.34894(m)	0.47889(m)

VI. PSEUDO-LOS COMMAND SIMULATION

The guidance scheme of the lead angle command is almost the same as that of the basic LOS command. Instead of the tracker-to-target line-of-sight this guidance scheme uses the tracker-to-estimated impact point and is called "synthetic line-of-sight" (SLOS), or "pseudo line-of-sight". The missile is controlled to fly along this pseudo line-of-sight. The block diagram of this system is easily modified from that of the basic LOS and is shown in Figure 6.1.

The estimated impact point at the instantious time is calculated by using the "time to go" (Tg) and the "closing velocity" (Vc) between the target and the missile.

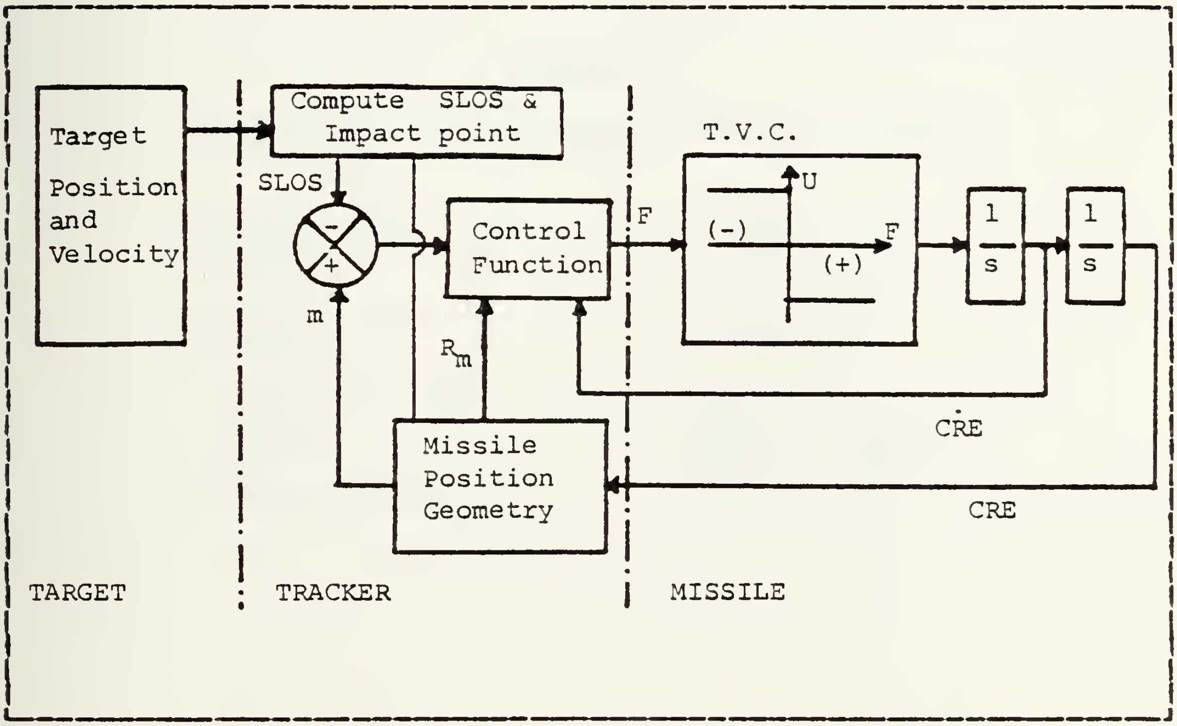


Figure 6.1 Block Diagram of the Pseudo LOS Command System

The "closing velocity" and "time to go" are calculated as follow:

$$Vc = \left((Vtx-Vmx)^2 + (Vty-Vmy)^2\right)^{\frac{1}{2}}$$

$$Tg = (\text{distance between target and missile}) \,/\, Vc$$

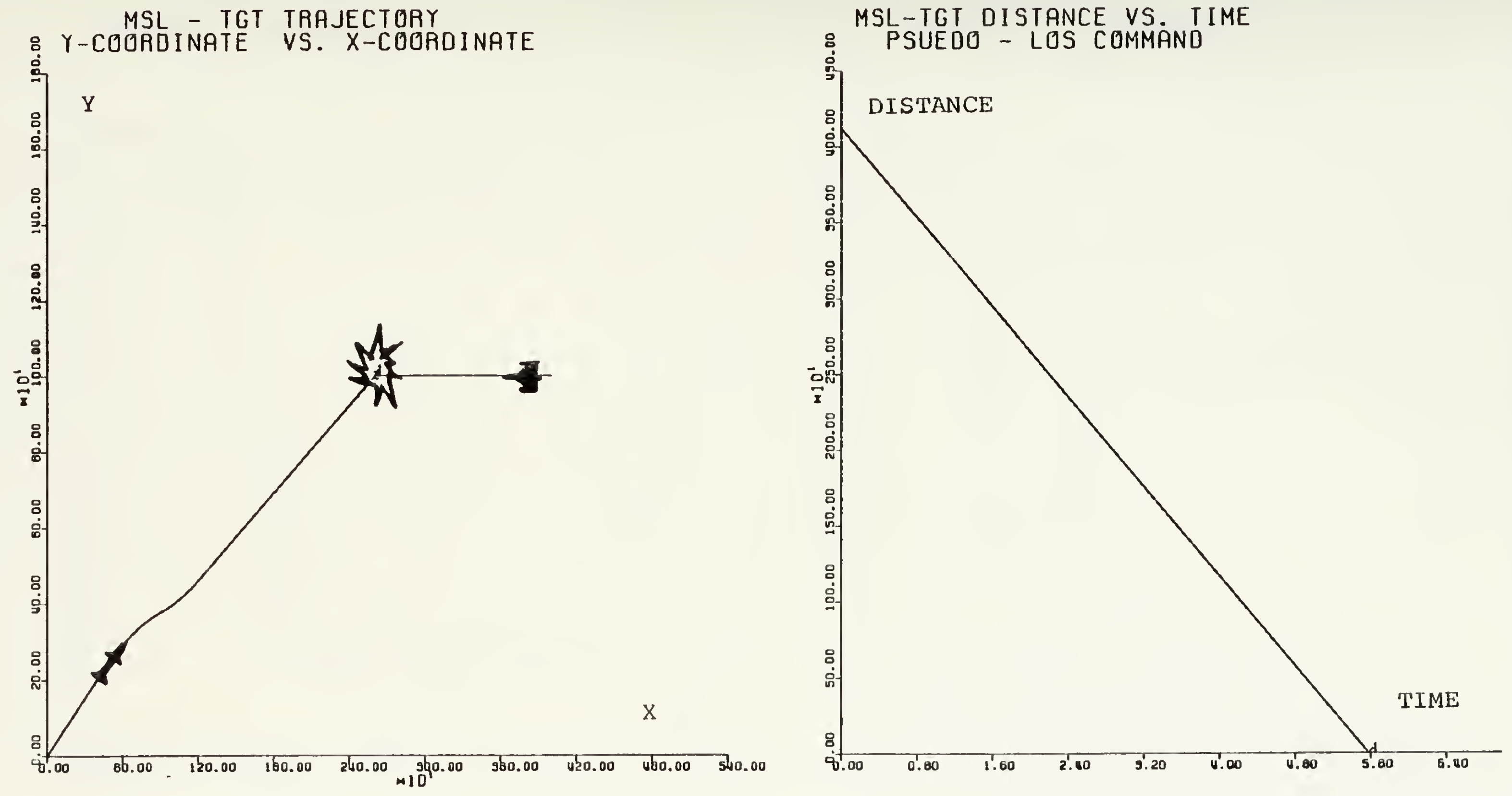
$$= \left((Xt-Xm)^2 + (Yt-Ym)^2\right)^{\frac{1}{2}} \,/\, Vc$$

The missile goes to the impact point directly. The simulation result is almost same as in the basic LOS case. On other hand, this guidance scheme is poor in a ECM situation. In order to compare the results we used the same data as that of the basic LOS command. These are shown in Figures 6.2 through 6.5 and the summarized results are shown in Table II. The computer program is attached in Appendix E.

TABLE II

The Pseudo LOS Command Simulation Result

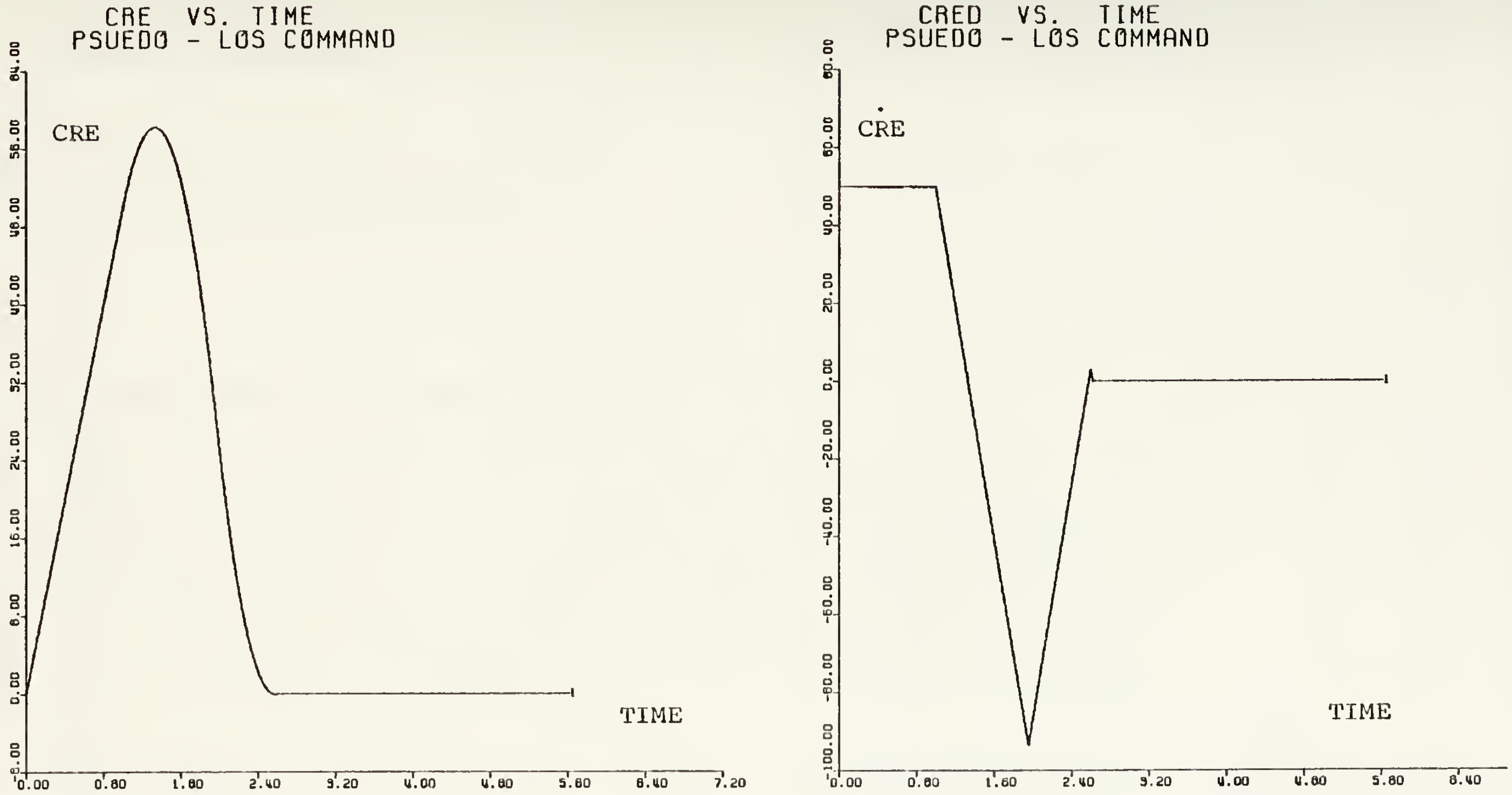
.time(control)	1.0 sec
CRE(0)	49.912 (m)
CRED(0)	49.828 (m/sec)
.time(MAX.CRE)	1.33 sec
CRE(max)	58.184 (m)
.time(intercept)	5.58 sec
(Xm,Ym)	(2604.7, 999.92)
(Xt,Yt)	(2605.0, 1000.0)
CRE	2.9572 E-5(m)
miss-distance	0.35137 (m)



(a) Missile-Target Trajectory

(b). Missile-Target Distance versus Time

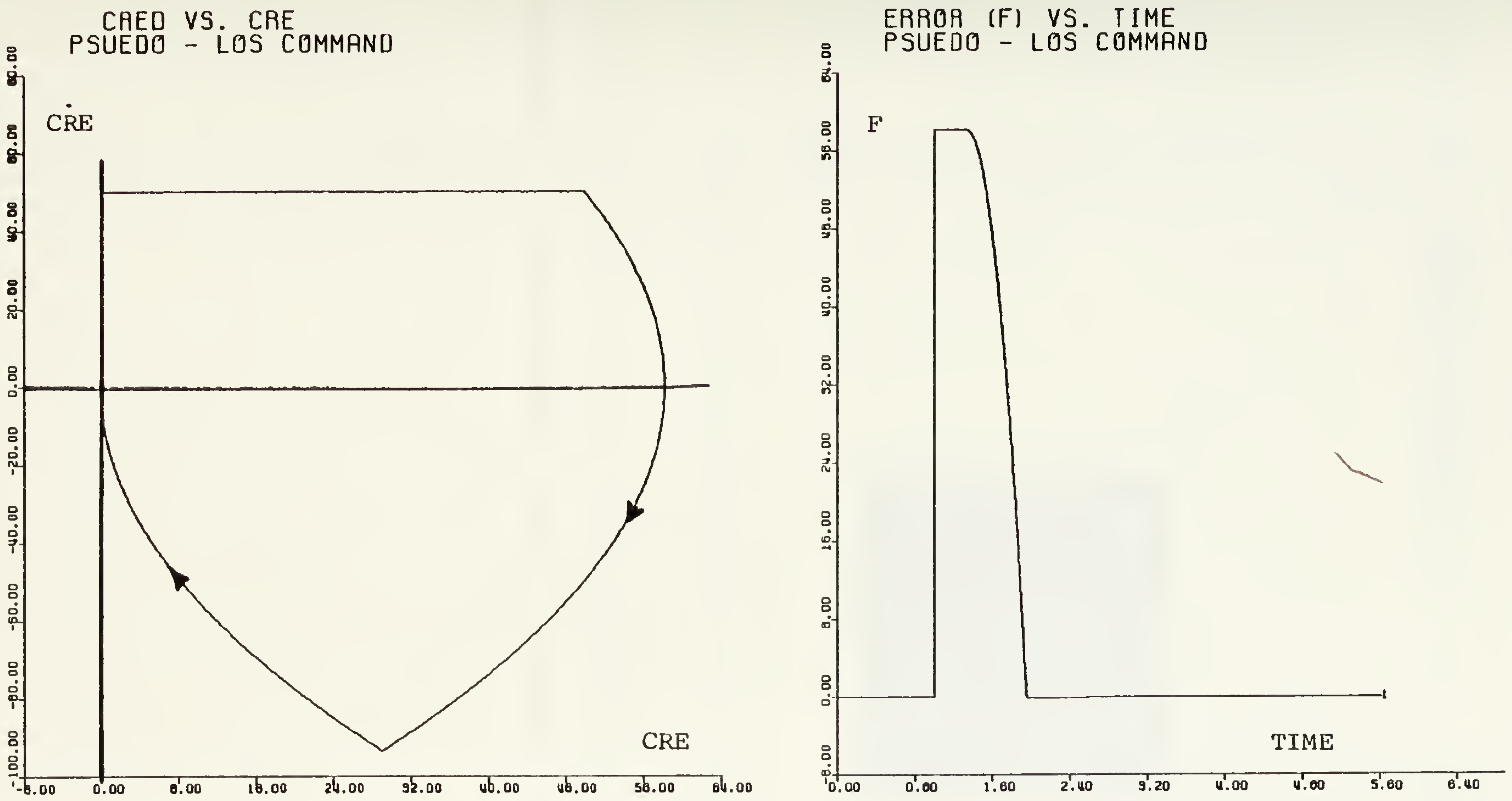
Figure 6.2 The Pseudo-LOS Command



(a). CRE versus Time

(b). $\dot{CRE}$ versus Time

Figure 6.3 The Pseudo-LOS Command



(a). $\dot{\text{CRE}}$ versus CRE

(b). F versus Time

Figure 6.4 The Pseudo-LOS Command

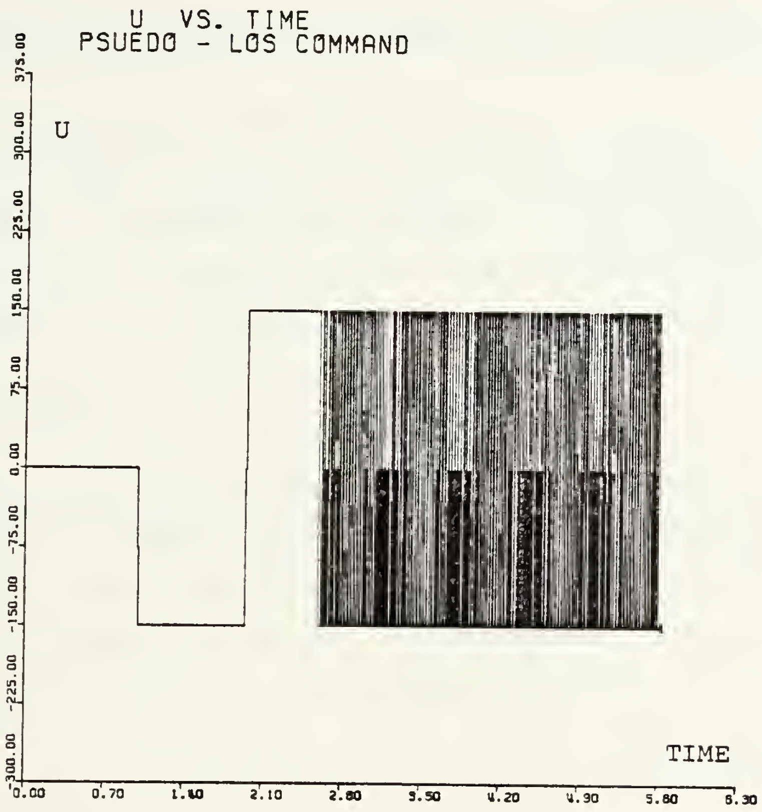


Figure 6.5 U versus Time for the Pseudo-LOS Command

VII. SIMULATIONS WITH TWO-LEVEL RELAY AND SATURATION CONTROL

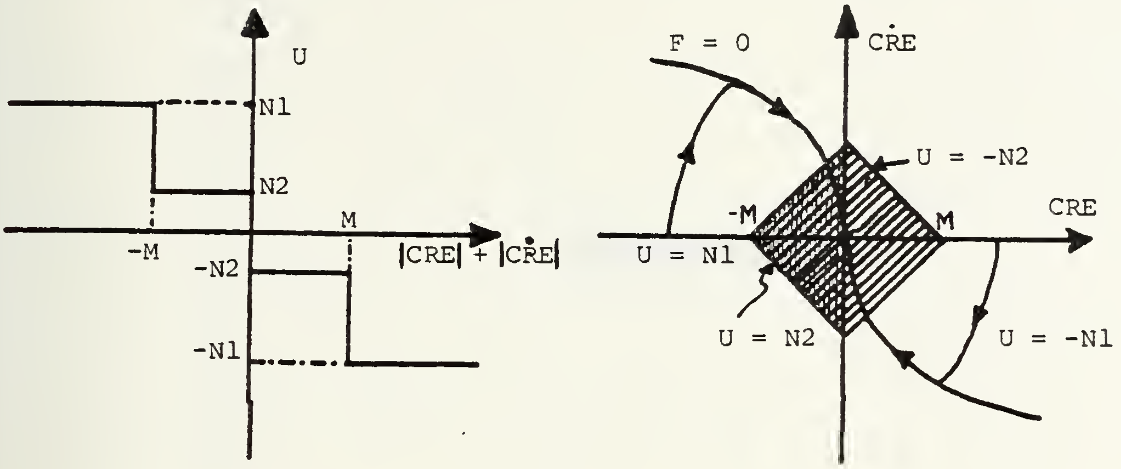
The LOS guidance with an "ideal" relay has been discussed. In this chapter, the effect of the different types of lateral acceleration demand are discussed. In order to compare the results with the previous simulations, the same parameters were used.

A. TWO-LEVEL RELAY

The large magnitude of the LATAX makes a fast response. But in the case of small CRE, a smaller magnitude of LATAX is needed. This idea was developed in a "two-level" relay as shown on the Figures 7.1(a;b). The shaded area on Figure 7.2(b) shows the region of a lower level of LATAX in the "$\dot{\text{CRE}}$ verse CRE" phase plain. It provided the minimum over-correction. The computer programs were easily modified by adding one statement,

```
IF ((|CRE|+|CRED|).LT. M) G = G/(N1/N2).
```

We used the values 150 m/sec^2 for N1 and 15 m/sec^2 for N2 and 1.0 for M in the simulations of the basic LOS command and the pseudo LOS command. The results were almost the same as the previous, except in the figure for "U versus time". Table III summarized these simulation results and Figures 7.2, 7.3 and 7.4 show the "U versus time" of each case. The programs were attached in Appendix F, G and H.



(a). U versus $|CRE| + |\dot{CRE}|$ (b). $\dot{CRE}$ versus CRE

Figure 7.1 Two-Level Relay

TABLE III

Two-Level Relay Control Result

UNIT	NON-MVR	MVR-TGT	PSEUDO-LOS
.time(control)	1.0	1.0	1.0
CRE(0)	49.910	49.907	49.910
CRED(0)	49.832	49.891	49.828
.time(MAX.CRE)	1.33	1.33	1.33
CRE(max)	58.184	58.201	58.184
.time(intercept)	5.58	5.61	5.58
Xm	2604.7	2597.9	2604.7
Ym	999.88	1057.7	999.92
Xt	2605.0	2597.5	2605.0
Yt	1000.0	1057.5	1000.0
CRE	-2.63E-6	-3.63E-6	5.03E-8
miss-distance	0.34894	0.47889	0.35137

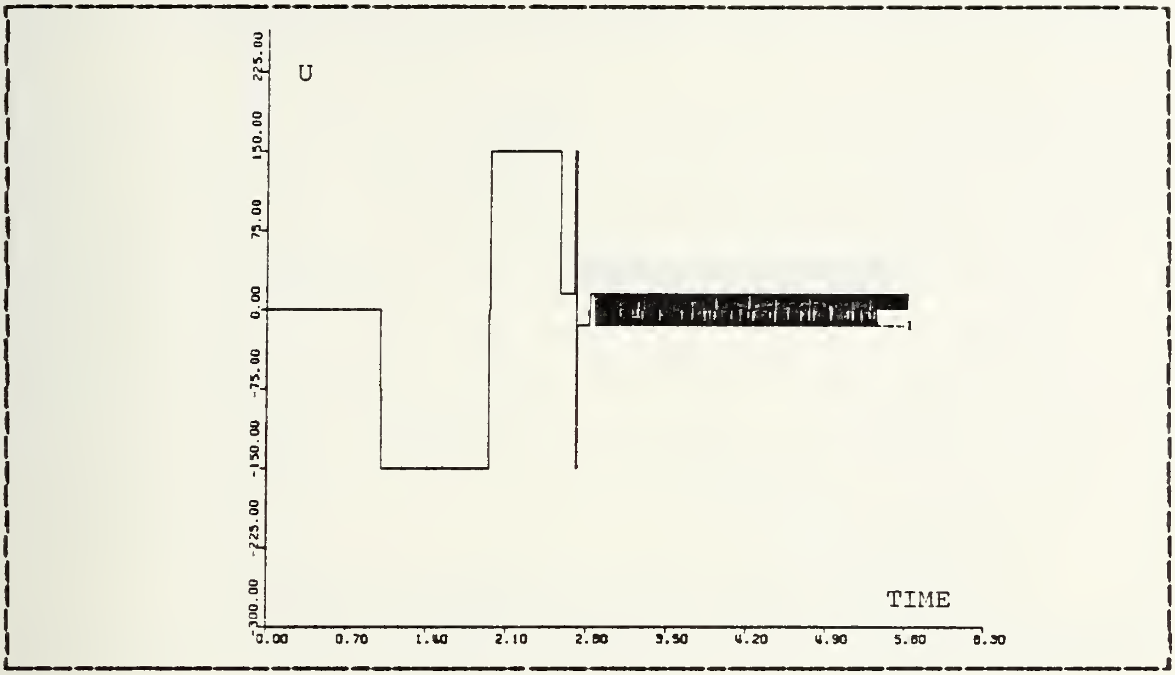


Figure 7.2 U versus Time for the Basic LOS Guidance

B. SATURATING LINEAR CONTROL

In the previous section the two-level relay was discussed. The "sautrating linear control" as depicted in the Figure 7.5(a) and 7.5(b) was also studied. The shaded area on the Figure 7.5(b) shows the region of linear control in the "$\dot{\mathrm{CRE}}$ versus CRE" phase plane. The computer programs were easily modified by adding one statement,

```
    IF (ABS(F).LE.M) U = -G * F / M.
```

The value of "M" determines the linear region for F. The Figures 7.6 through 7.8 show the simulation results of the basic LOS command against the non-maneuvering target case for "M" equal 1, 5 and 10. When choosing the value "M" equal to "one", the intercept time and miss distance are almost the same as the counterpart of the ideal relay case. Hence the saturating linear control can be used in practice

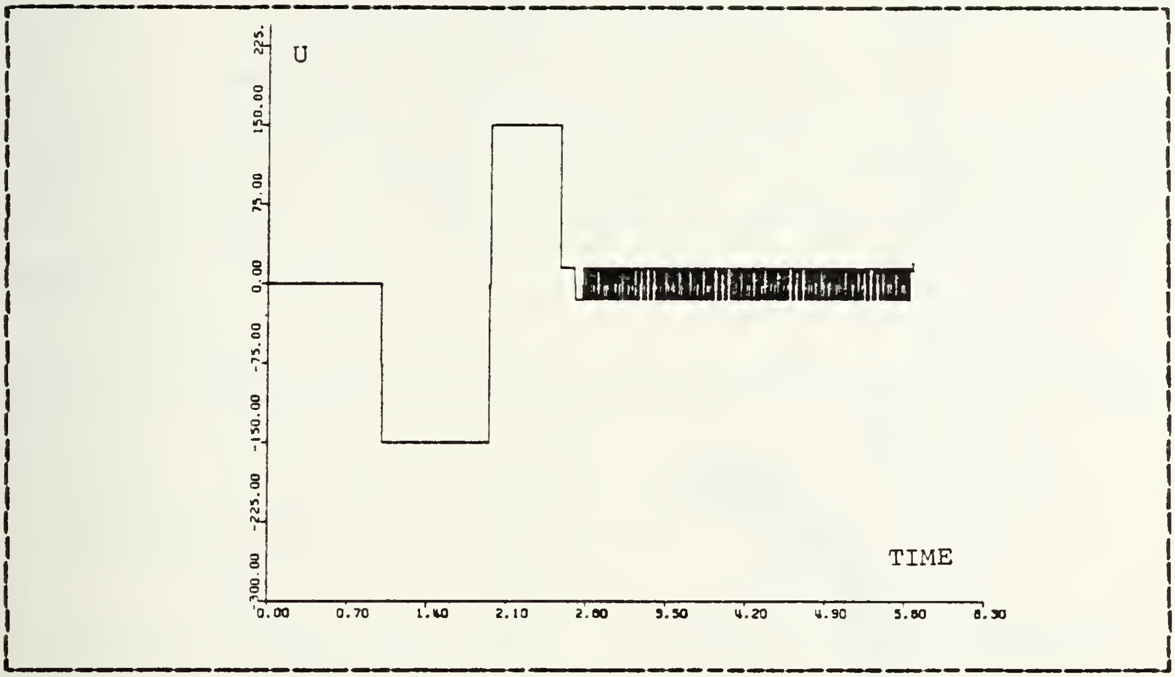


Figure 7.3 U verse Time against the MVR Target with Two-Level Relay

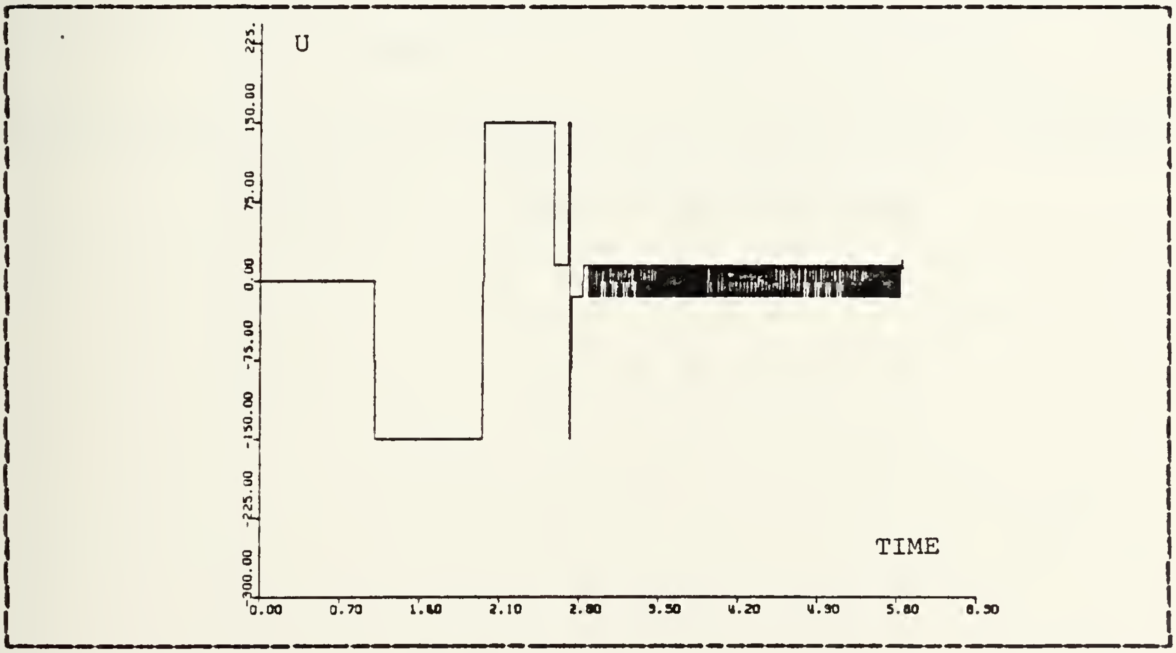
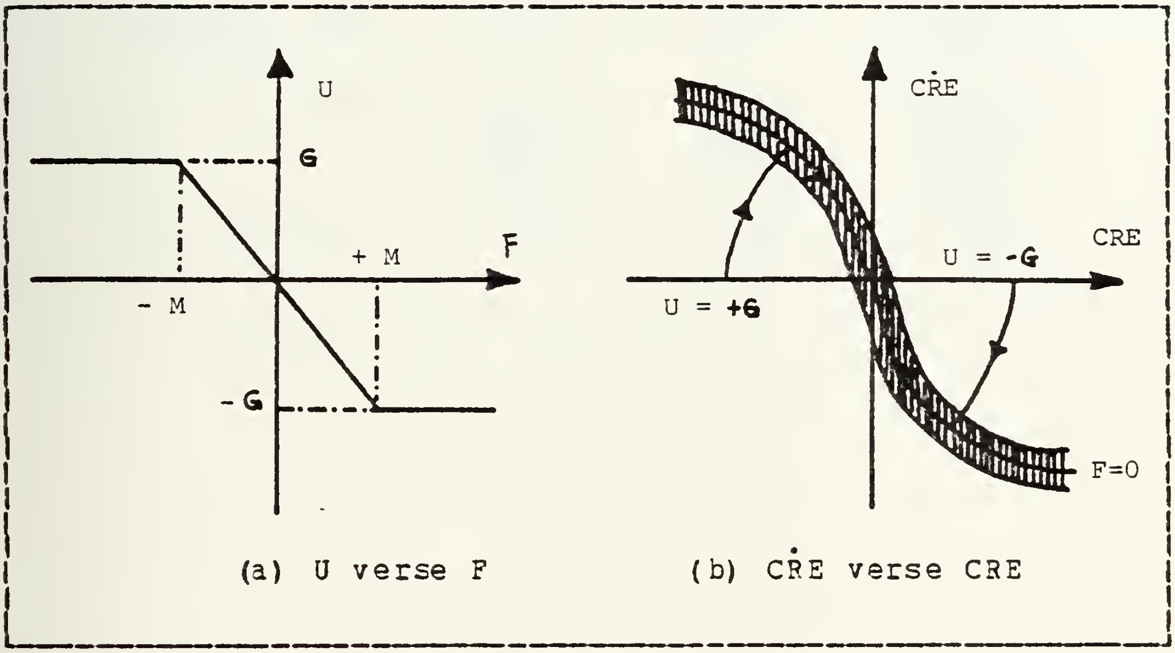


Figure 7.4 U verse Time of the Pseudo-LOS with Two-Level Relay

instead of the ideal relay by choosing a proper value of "M". The summarized results are in the Table IV.
Figures 7.9 through 7.11 show the results of the maneuvering target case and Figures 7.12 through 7.14 show the results of the pseudo-LOS case. These programs are given in Appendix I, J and K.



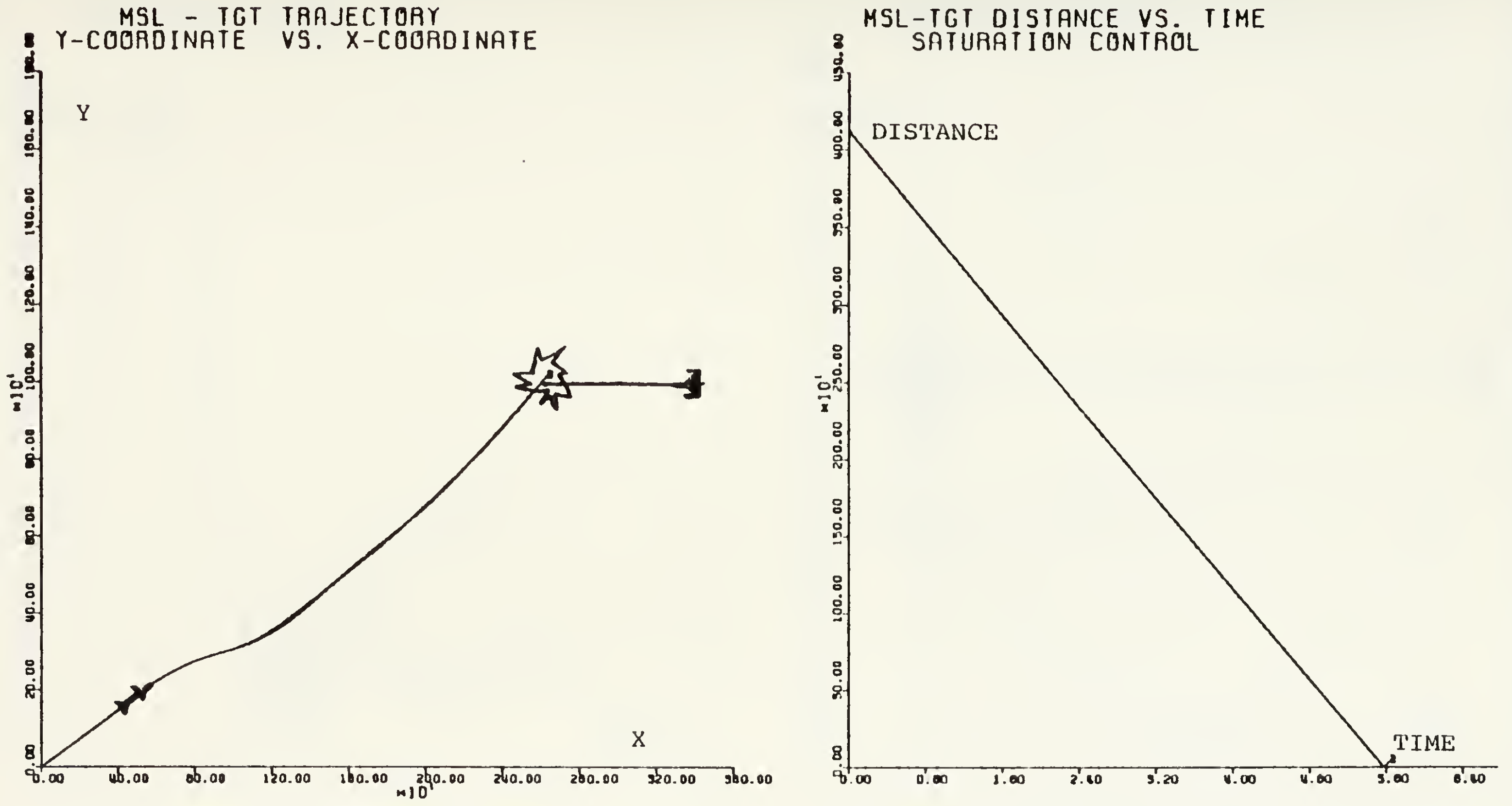
(a) U verse F (b) $\dot{CRE}$ verse CRE

Figure 7.5 Linear Switching Relay

TABLE IV

Saturating Linear Control Result (M=1)

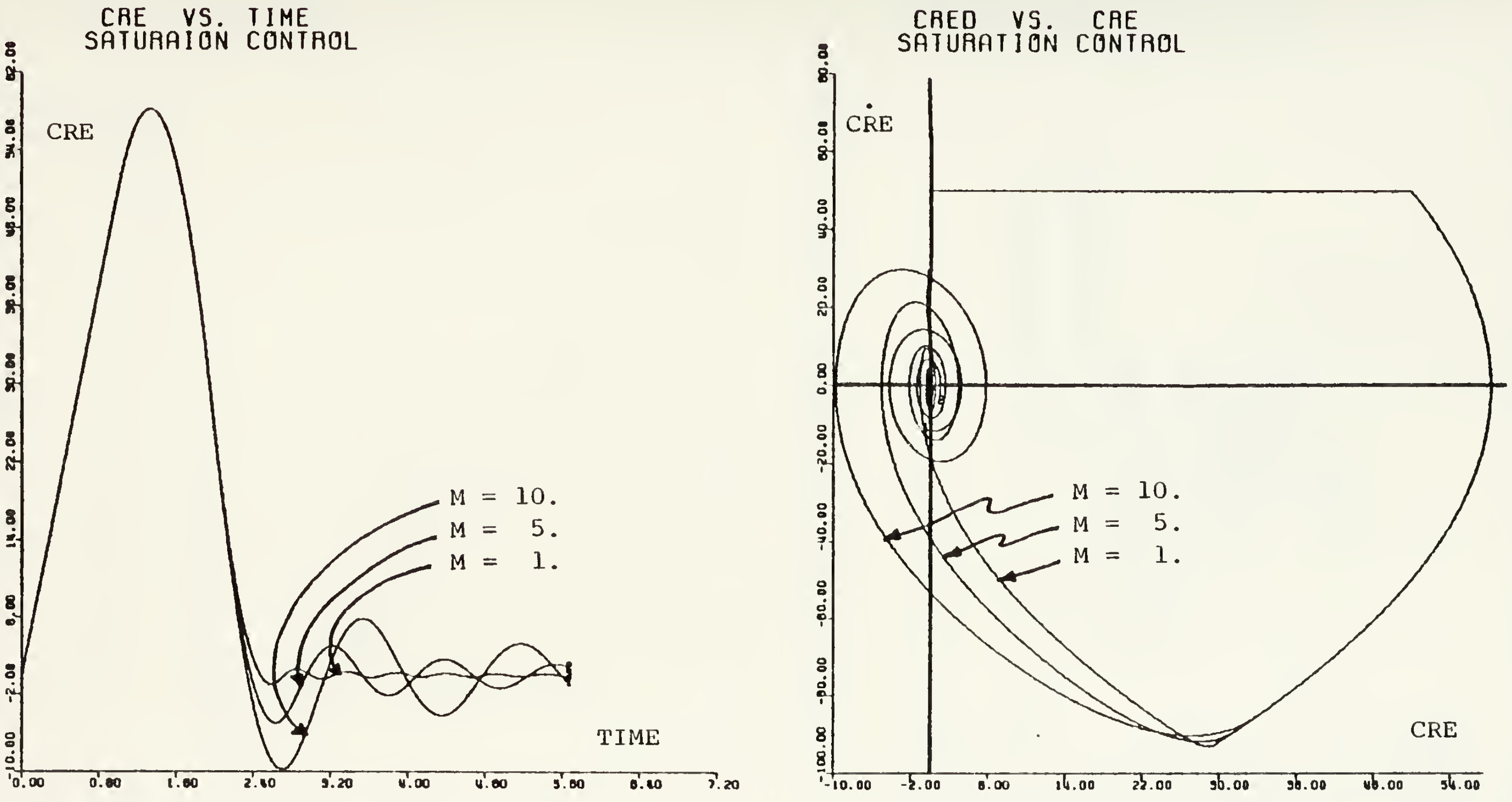
UNIT	NON-MVR	MVR-TGT	PSEUDO-LOS
.time(control)	1.0	1.0	1.0
CRE(0)	49.910	49.907	49.912
CRED(0)	49.832	49.891	49.828
.time(MAX. CRE)	1.33	1.33	1.33
CRE(max)	58.184	58.201	58.184
.time(intercept)	5.58	5.61	5.58
Xm	2604.7	2598.0	2604.7
Ym	999.84	1057.6	999.88
Xt	2605.0	2597.5	2605.0
Yt	1000.0	1057.5	1000.0
CRE	-.0349	-.0702	-.0349
miss-distance	0.3507	0.4841	0.3492



(a). Missile-Target Trajectory

(b). Missile-Target Distance versus Time

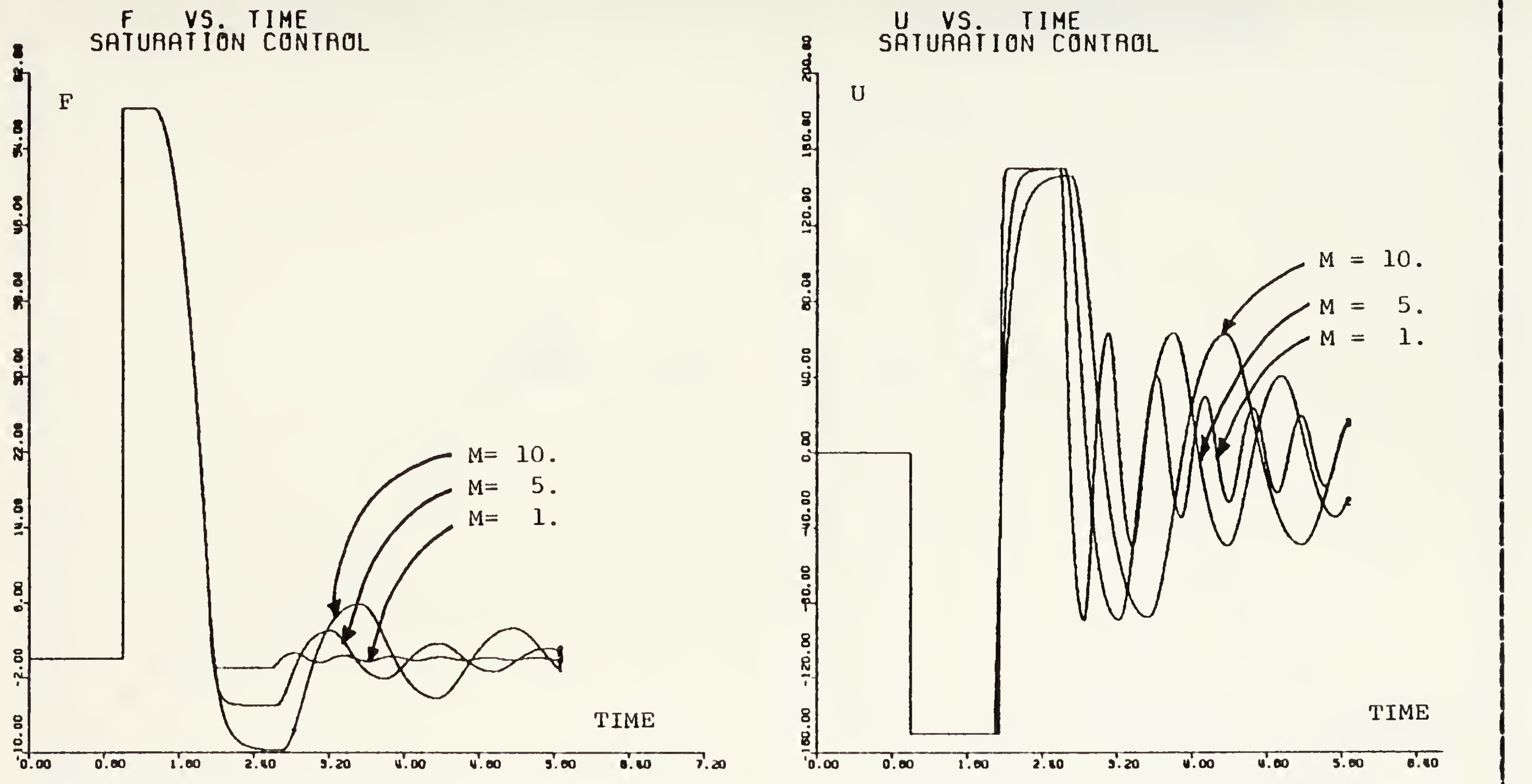
Figure 7.6 The Basic LOS Command (Saturation)



(a). CRE versus Time

(b). C$\dot{R}$E versus CRE

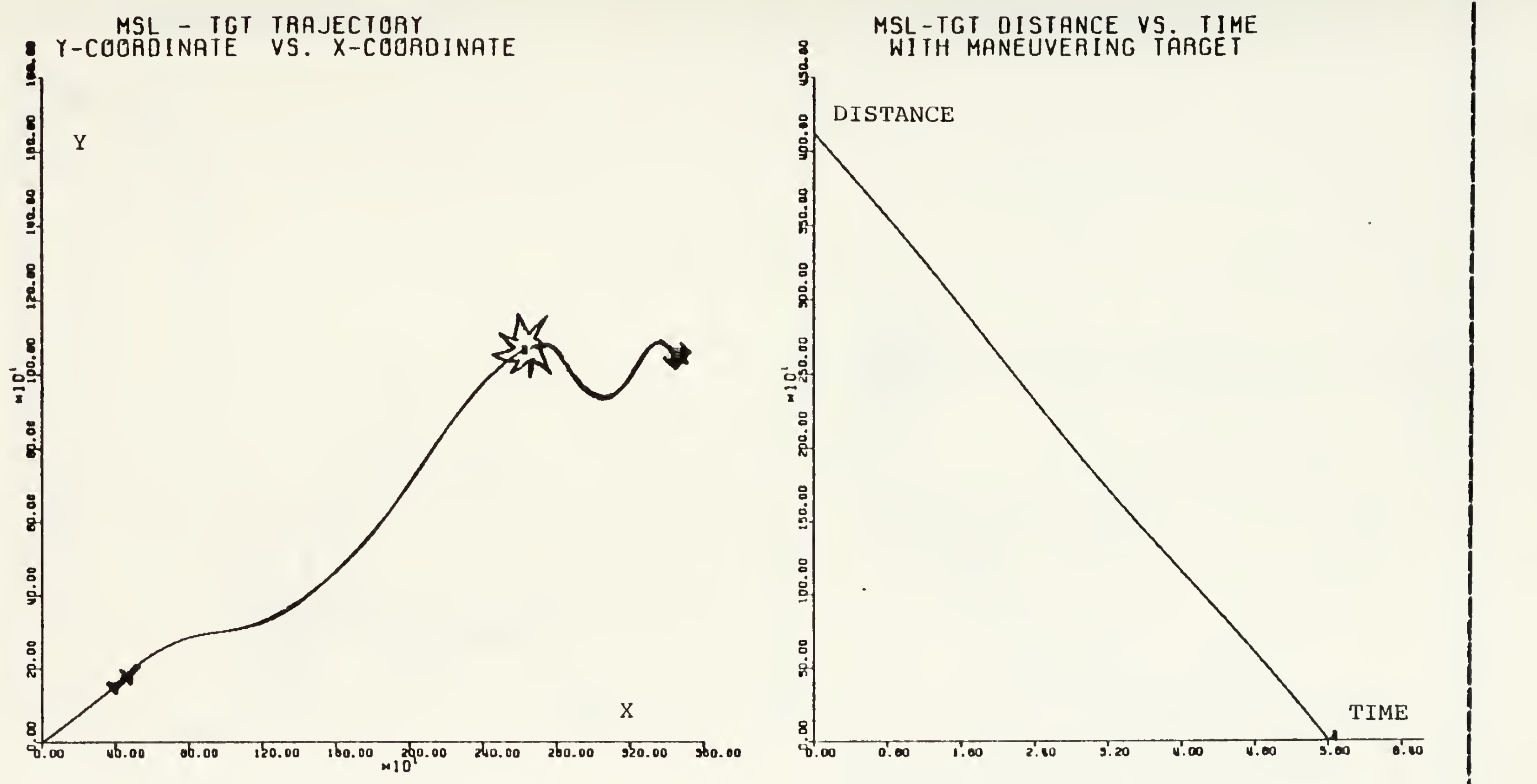
Figure 7.7 The Basic LOS Command (Saturation)



(a). F versus Time

(b). U versus Time

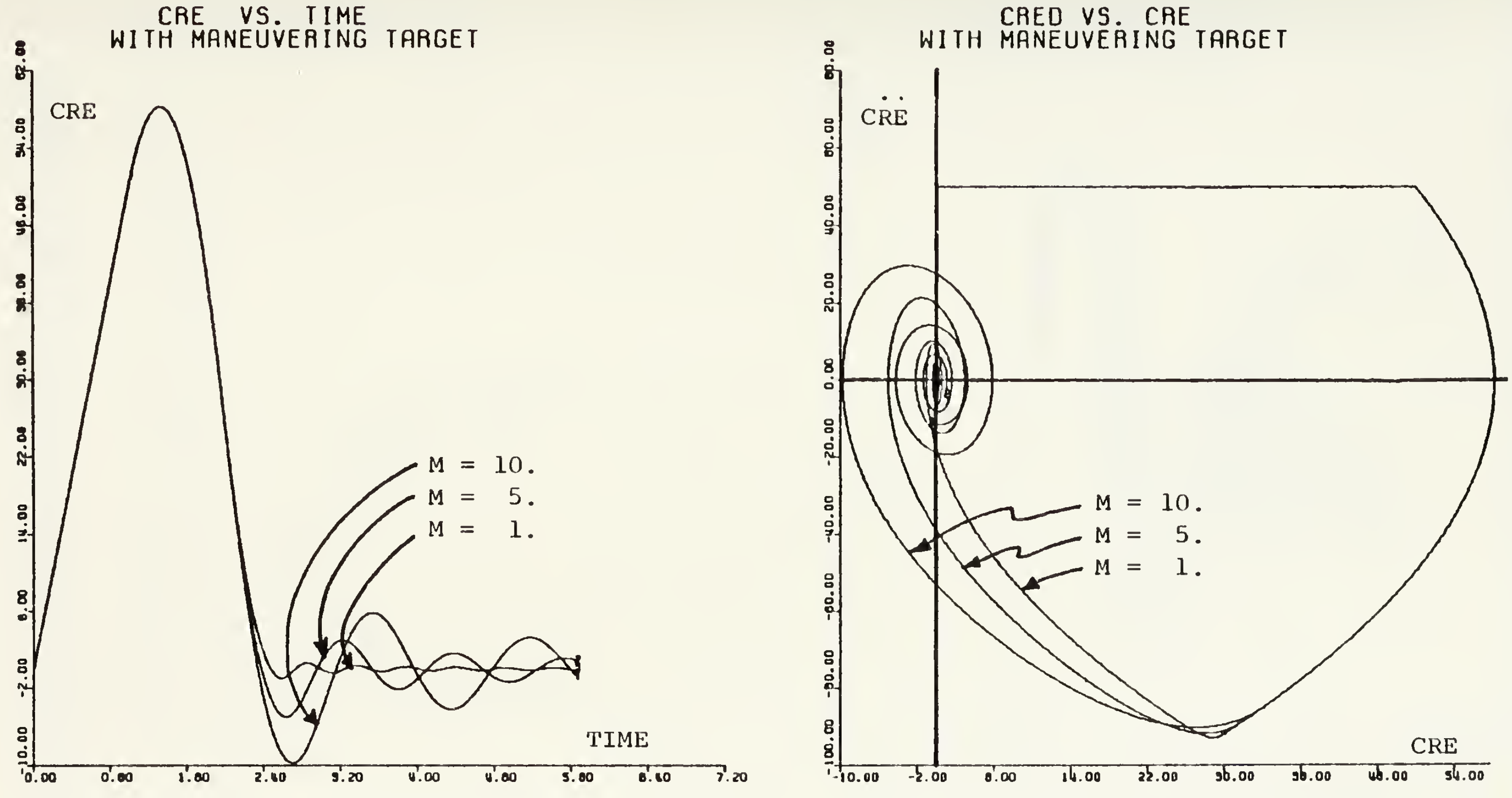
Figure 7.8 The Basic LOS Command (Saturation)



(a). Missile-Target Trajectory

(b). Missile-Target Distance versus Time

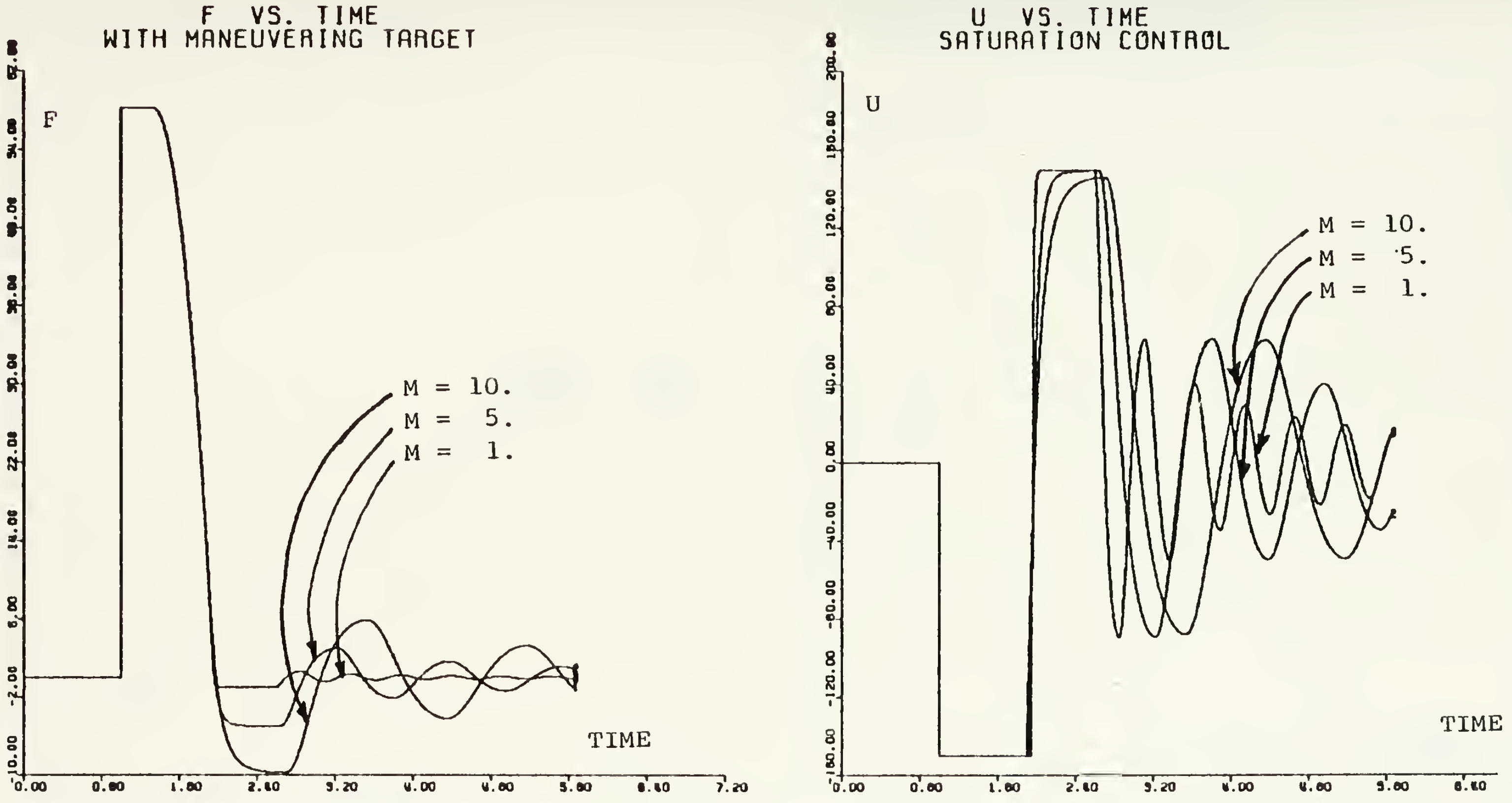
Figure 7.9 Maneuvering Target (Saturation)



(a). CRE versus Time

(b). $\dot{\text{CRE}}$ versus CRE

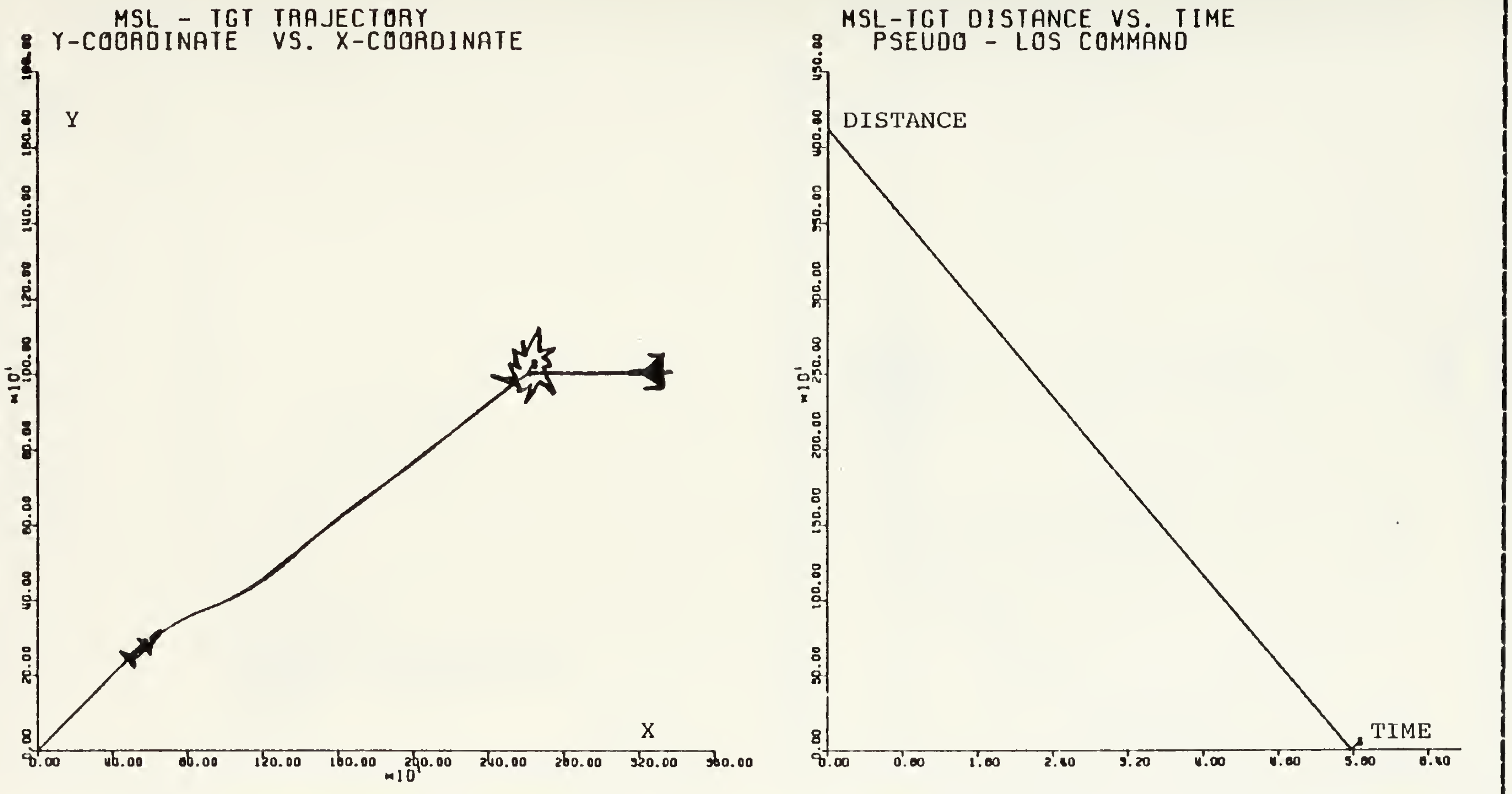
Figure 7.10 Maneuvering Target (Saturation)



(a). F versus Time

(b). U versus Time

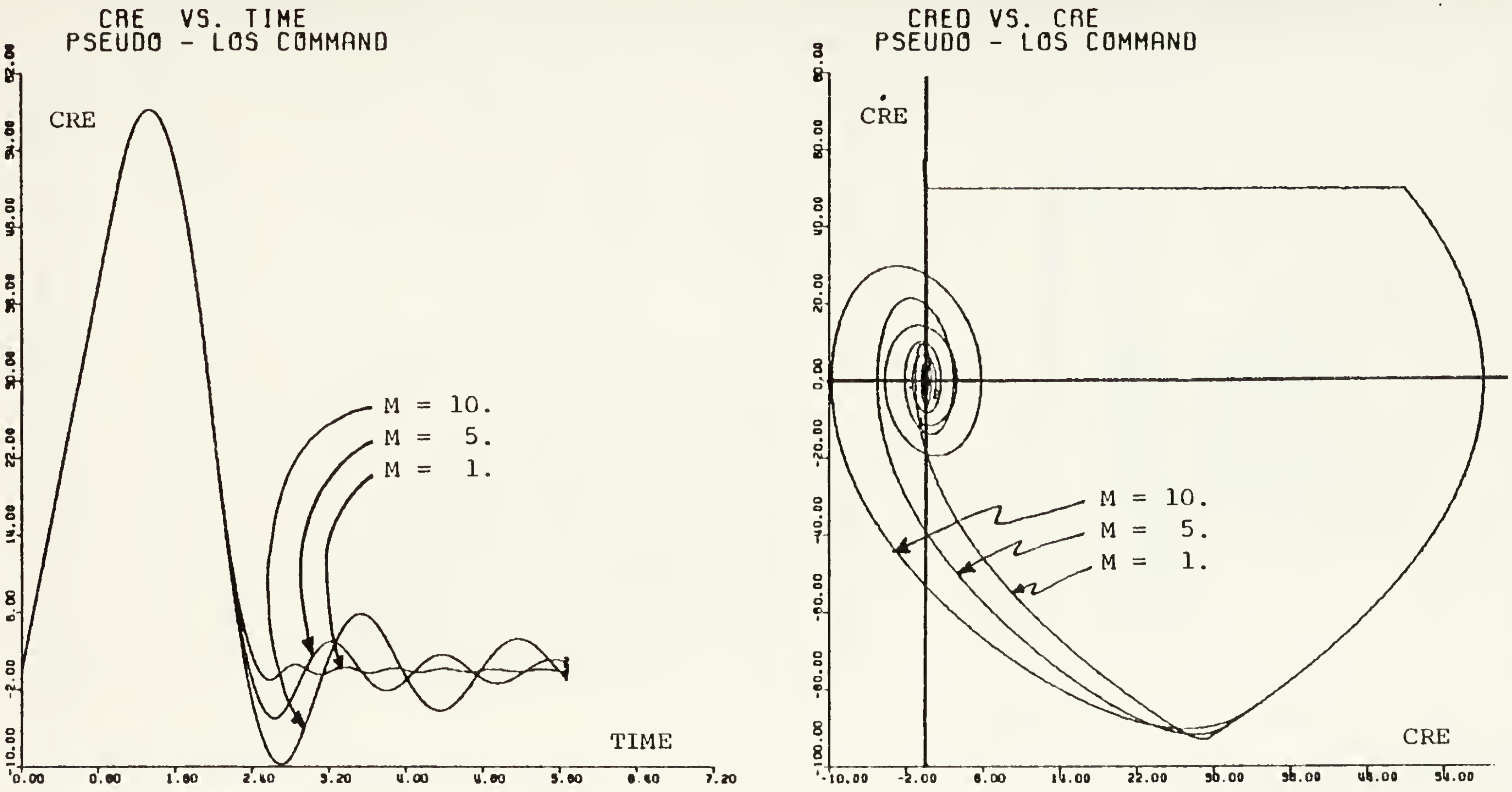
Figure 7.11 Maneuvering Target (Saturation)



(a). Missile-Target Trajectory

(b). Missile-Target Distance versus Time

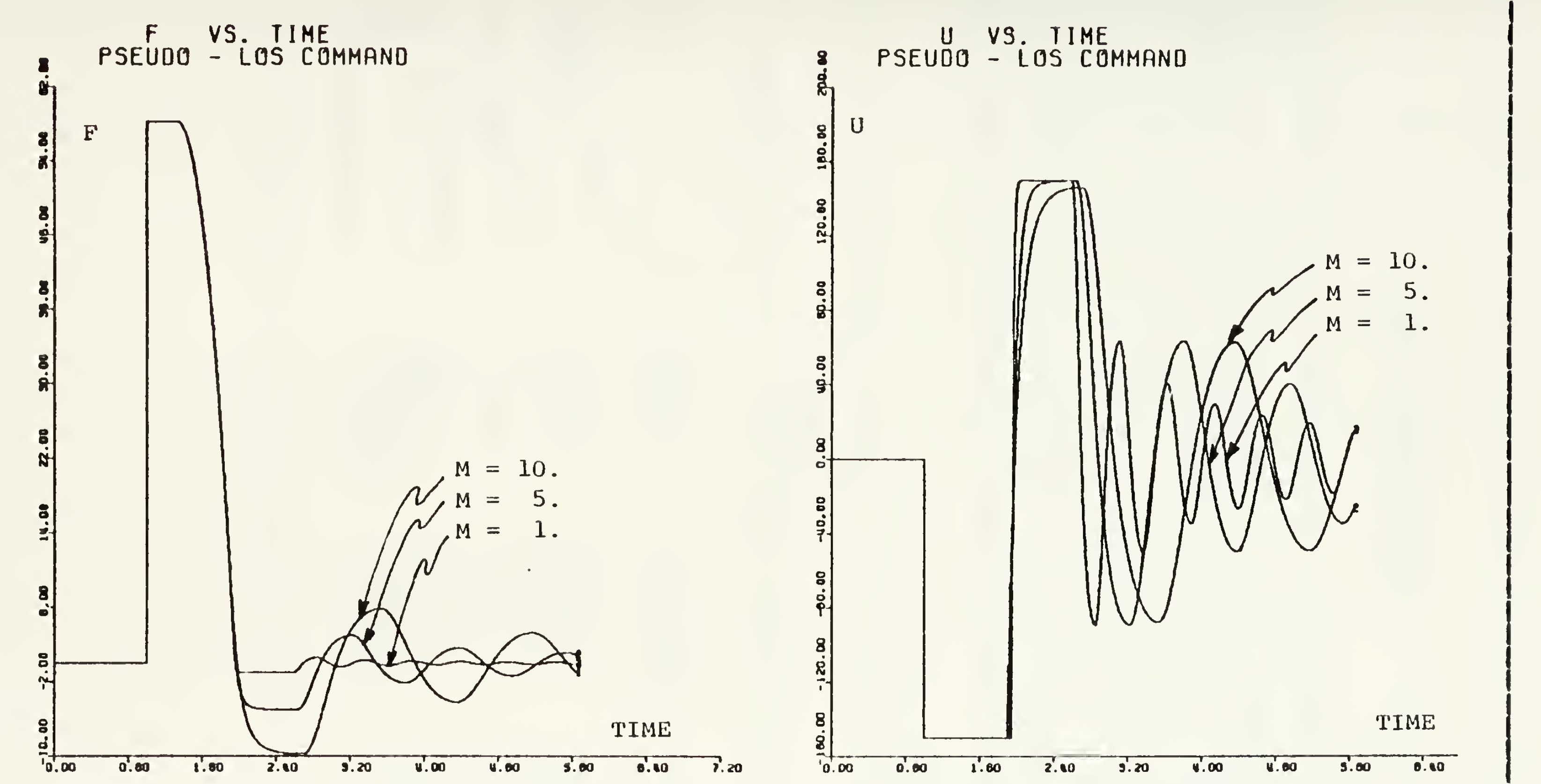
Figure 7.12 Pseudo-LOS Command (Saturation)



(a). CRE versus Time

(b). $\dot{CRE}$ versus CRE

Figure 7.13 Pseudo-LOS Command (Saturation)



(a). F versus Time

(b). U versus Time

Figure 7.14 Pseudo-LOS Command (Saturation)

VIII. CONCLUSION

The comparision of results for the ideal relay, two-level relay and saturating linear control against the basic LOS command and pseudo-LOS command against a non-maneuvering target and maneuvering target are provided in the Tables V, VI and VII. These simulation results clearly demonstrate that "on-off" control of a missile is highly desireable and that "saturating linear control" of a missile has little adverse effects compared to an "ideal relay" control.

TABLE V

Comparison of the Basic LOS Command Results

UNIT	IDEAL RELAY	TWO-LEVEL RELAY	SATURATION CONTROL
.time(control)	1.0	1.0	1.0
CRE(0)	49.910	49.910	49.910
CRED(0)	49.832	49.832	49.832
.time(MAX.CRE)	1.33	1.33	1.33
CRE(max)	58.184	58.184	58.184
.time(intercept)	5.58	5.58	5.58
Xm	2604.7	2604.7	2604.7
Ym	999.88	999.88	999.88
CRE	4.33E-5	4.33E-5	4.33E-5
miss-distance	0.34894	0.34894	0.34894

TABLE VI

Comparison of the Maneuvering Target Results

UNIT	IDEAL RELAY	TWO-LEVEL RELAY	SATURATION CONTROL
.time(control)	1.0	1.0	1.0
CRE(0)	49.907	49.907	49.907
CRED(0)	49.891	49.891	49.891
.time(MAX.CRE)	1.33	1.33	1.33
CRE(max)	58.201	58.201	58.201
.time(intercept)	5.61	5.61	5.61
Xm	2597.5	2597.5	2597.5
Ym	1057.5	1057.5	1057.5
CRE	-6.54E-6	3.63E-6	-0.0702
miss-distance	0.47889	0.47889	0.4841

TABLE VII

Comparison of the Pseudo-LOS Command Results

UNIT	IDEAL RELAY	TWO-LEVEL RELAY	SATURATION CONTROL
.time(control)	1.0	1.0	1.0
CRE(0)	49.912	49.910	49.912
CRED(0)	49.828	49.828	49.828
.time(MAX.CRE)	1.33	1.33	1.33
CRE(max)	58.184	58.184	58.184
.time(intercept)	5.58	5.58	5.58
Xm	2604.7	2604.7	2604.7
Ym	999.92	999.92	999.92
CRE	2.96E-5	5.03E-8	2.96E-5
miss-distance	0.35137	0.35137	0.35137

APPENDIX A

VARIABLES LIST

DIAGRAM VARIABLES	COMPUTER VARIABLES	NOUN DESCRIPTION
CRE	CRE	cross-range-error
$\dot{CRE}$	CRED	rate of cross-range-error change
F	F	error function
G	G	magnitude of lateral acceleration
U	U	missile's lateral acceleration
σ_t	SIGT	angle between the LOS to target and X-axis
σ_m	SIGM	angle between the beam to missile and X-axis
σ_{mt}	SIGMT	angle difference between m and t
Vc	VC	crossing velocity
tg	TG	time to go
t(control)	TCON	beginning time of on-off control
SLOS	SLOS	synthetic line-of-sight
Xm	XM	X-coordinate of missile position
Ym	YM	Y-coordinate of missile position
Xt	XT	X-coordinate of target position
Yt	YT	Y-coordinate of target position
Vm	VM	velocity of the missile
Vt	VT	velocity of the target
Vmx	VMX	X-component of missile's velocity
Vmy	VMY	Y-component of missile's velocity
Vtx	VTX	X-component of target's velocity
Vty	VTY	Y-component of target's velocity

APPENDIX B

PROGRAM OF THE SWICHING FUNCTION

```
TITLE         BANG-BANG CONTROL
TITLE       SWITCHING   FUNCTION
TITLE          * YEUN, J.Y. *
INTGER      NPLOT
CONST       NPLOT=1
INITIAL
            CRE  = 1.0
            CRED = 0.
            ACRED = 0.
**********
DERIVATIVE
**********
NOSORT
*
            G = 1.0
            F = CRE   +  (CRED*ACRED)/(2*G)
            U = -G * SIGN(1.,F)
            CRED = INTGRL(0.,U)
            CRE  = INTGRL(CRE,CRED)
            ACRED = ABS(CRED)
            IF(CRE.LE. 0.0) CALL ENDJOB
SAMPLE
            CALL DRWG(1,1,TIME,CRE)
            CALL DRWG(2,1,CRE,CRED)
            CALL DRWG(3,1,TIME,F)
            CALL DRWG(4,1,TIME,CRED)
            CALL DRWG(5,1,TIME,U)
TERMINAL
            CALL ENDRW(NPLOT)
CONTRL FINTIM=2.1,DELT=0.01,DELS=0.01
PRINT     0.1,G,F,U,CRE,CRED
END
STOP
```

APPENDIX C

PROGRAM OF THE BASIC COMMAND TO LOS

```
TITLE    BASIC COMMAND TO L.O.S
TITLE      WITH IDEAL RELAY
TITLE    ***** YEUN, J.Y. *****
INTEG    RKSFX
INTGER   NPLOT,KILL
CONST    NPLOT=1,TCON=1.0
CONST    VM=500.,VT=250,PI=3.141593,KILL=0
INITIAL
         XT0 = 4000.
         YT0 = 1000.
         GAMT =  PI
         F   = 0.
*
*************************************************************
DERIVATIVE
*************************************************************
NOSORT
*************************
*** TARGET PARAMETERS ***
*************************
         VTX = VT*COS(GAMT)
         VTY = VT*SIN(GAMT)
         XT = VTX*TIME + XT0
         YT = VTY*TIME + YT0
         SIGT = ATAN2(YT,XT)
         IF (TIME.GE.TCON)  GO TO 50
*************************
*** MISSLE PARAMETERS ***
*************************
* PROGRAMMED GUIDANCE ***************************************
*
         SIGM =  SIGT+0.1
         VXM = VM * COS(SIGM)
         VYM = VM *  SIN(SIGM)
         XM  = INTGRL(0.,VXM)
         YM  = INTGRL(0.,VYM)
         RM  = SQRT(XM**2 + YM**2)
         SIGMT = SIGM - SIGT
         CRE = RM * SIN(SIGMT)
         CRED = DERIV(0.,CRE)
         GO TO 200
*****************************
* ON-OFF GUIDANCE (BANG-BANG CONTROL) *********************
*****************************
*
   50    CONTINUE
*

         G = 150.
         ACRED = ABS(CRED)
         F = CRE + (CRED*ACRED)/(2*G)
         U = -G * SIGN(1.,F)
         CRED = INTGRL(0.0, U)
         CRE = INTGRL(CRE,CRED)
*
         RM  = VM*TIME
         A3  = CRE/RM
         SIGMT = ARSIN(A3)
         SIGM = SIGT + SIGMT
```

```
         XM   =  RM  *  COS(SIGM)
         YM   =  RM  *  SIN(SIGM)
**********************************************************
  200    CONTINUE
*
**********************************************************
*** MISSION RESULT ***  KILL = 0  ;  TGT  MISSED
**********************  KILL = 1  ;  TGT  DESTROYED
         XDIST = XT-XM
         YDIST = YT-YM
         DIST  = SQRT(XDIST**2 + YDIST**2)
         IF (DIST .LE.5)  KILL = 1
         IF (DIST .GT.5)  KILL = 0
         IF (XM .GT. (XT+30))CALL ENDJOB
*
SORT
**********************************************************
******** OUTPUT AND PLOT CONTROL CARD ********************
**********************************************************
SAMPLE
         CALL DRWG(1,1,XM,YM)
         CALL DRWG(1,2,XT,YT)
         CALL DRWG(2,1,TIME,DIST)
         CALL DRWG(3,1,TIME,CRE)
         CALL DRWG(4,1,TIME,CRED)
         CALL DRWG(5,1,CRE,CRED)
         CALL DRWG(6,1,TIME,F)
         CALL DRWG(7,1,TIME,U)
TERMINAL
         CALL ENDRW(NPLOT)
CONTRL FINTIM=6.0,DELT=0.001,DELS=0.003
PRINT   0.005,XM,YM,XT,YT,CRE,CRED,DIST,KILL
END
STOP
```

APPENDIX D

PROGRAM OF THE MANEUVERING TARGET

```
TITLE    BASIC COMMAND TO LOS
TITLE    WITH MANEUVERING TGT
TITLE    ***  YEUN, J.Y.  ***
INTEG    RKSFX
INTGER   NPLOT,KILL
CONST    NPLOT=1,TCON=1.0
CONST    VM=500.,VT=250,PI=3.141593,KILL=0
INITIAL
         XT0 = 4000.
         YT0 = 1000.
         GAMT =  PI
         F = 0.
*
************************************************************
DERIVATIVE
************************************************************
NOSORT
*************************
*** TARGET PARAMETERS ***
*************************
         VTX = VT*COS(GAMT)
         VTY = VT*SIN(GAMT)
         XT = VTX*TIME + XT0
         YT = 100*SIN(0.5*PI*TIME) +YT0
         SIGT = ATAN2(YT,XT)
         IF (TIME.GE.TCON)  GO TO 50
*************************
*** MISSLE PARAMETERS ***
*************************
* PROGRAMMED GUIDANCE **************************************
*
         SIGM =  SIGT+0.1
         VXM = VM * COS(SIGM)
         VYM = VM * SIN(SIGM)
         XM  = INTGRL(0.,VXM)
         YM  = INTGRL(0.,VYM)
         RM  = SQRT(XM**2 + YM**2)
         SIGMT = SIGM - SIGT
         CRE = RM * SIN(SIGMT)
         CRED = DERIV(0.,CRE)
         GO TO 200
*****************************
* ON-OFF GUIDANCE (BANG-BANG CONTROL) *********************
*****************************
*
  50     CONTINUE
*
         G = 150.
         ACRED = ABS(CRED)
         F = CRE + (CRED*ACRED)/(2*G)
         U = -G * SIGN(1.,F)
         CRED =  INTGRL(0.0,U)
         CRE = INTGRL(CRE,CRED)
         ACRE =  ABS(CRE)
*
         RM  = VM*TIME
         A3  = CRE/RM
         SIGMT = ARSIN(A3)
         SIGM =  SIGT + SIGMT
```

```
         XM  = RM * COS(SIGM)
         YM  = RM * SIN(SIGM)
************************************************************
  200    CONTINUE
*
************************************************************
*** MISSION RESULT ***  KILL = 0 ;  TGT  MISSED
*********************** KILL = 1 ;  TGT  DESTROYED
         XDIST = XT-XM
         YDIST = YT-YM
         DIST  = SQRT(XDIST**2 + YDIST**2)
         IF (DIST .LE.5)  KILL = 1
         IF (DIST .GT.5)  KILL = 0
         IF (XM .GT. (XT+30))CALL ENDJOB
*
SORT
************************************************************
******** OUTPUT AND PLOT CONTROL CARD **********************
************************************************************
SAMPLE
         CALL DRWG(1,1,XM,YM)
         CALL DRWG(1,2,XT,YT)
         CALL DRWG(2,1,TIME,DIST)
         CALL DRWG(3,1,TIME,CRE)
         CALL DRWG(4,1,TIME,CRED)
         CALL DRWG(5,1,CRE,CRED)
         CALL DRWG(6,1,TIME,F)
         CALL DRWG(7,1,TIME,U)
TERMINAL
         CALL ENDRW(NPLOT)
CONTRL FINTIM=5.9,DELT=0.001,DELS=0.003
PRINT   0.005,XM,YM,XT,YT,CRE,CRED,DIST,KILL
END
STOP
```

APPENDIX E

PROGRAM OF THE COMMAND TO PSEUDO-LOS

```
TITLE     PSEUDO - LOS COMMAND
TITLE       WITH IDEAL RELAY
TITLE     ***  YEUN, J.Y. ***
INTEG     RKSFX
INTGER    NPLOT,KILL
CONST     NPLOT=1,TCON=1.0
CONST     VM=500.,VT=250,PI=3.141593,KILL=0
INITIAL
          XT0 = 4000.
          YT0 = 1000.
          TG = 0.
          F  = 0.
          GAMT = PI
*
************************************************************
DERIVATIVE
************************************************************
NOSORT
*************************
*** TARGET PARAMETERS ***
*************************
          VTX = VT*COS(GAMT)
          VTY = VT*SIN(GAMT)
          XT = VTX*TIME + XT0
          YT = VTY*TIME + YT0
          SIGT = ATAN2(YT,XT)
          XLOS = XT + VTX*TG
          YLOS = YT + VTY*TG
          SLOS = ATAN2(YLOS,XLOS)
          IF (TIME.GE.TCON) GO TO 50
*************************
*** MISSLE PARAMETERS ***
*************************
* PROGRAMMED GUIDANCE **************************************
*
          SIGM = SLOS + 0.1
          VMX = VM * COS(SIGM)
          VMY = VM * SIN(SIGM)
          XM  = INTGRL(0.,VMX)
          YM  = INTGRL(0.,VMY)
          RM  = SQRT(XM**2 + YM**2)
          SIGMS = SIGM - SLOS
          CRE = RM * SIN(SIGMS)
          CRED = DERIV(0.,CRE)
          GO TO 200
*****************************
* ON-OFF GUIDANCE (BANG-BANG CONTROL) **********************
*****************************
*
   50     CONTINUE
*
          G = 150.
          ACRED = ABS(CRED)
          F = CRE + (CRED*ACRED)/(2*G)
          U = -G * SIGN(1.,F)
          CRED = INTGRL(0.0,U)
          CRE = INTGRL(CRE,CRED)
*
          RM  = VM*TIME
```

```
         A3  = CRE/RM
         SIGMS = ARSIN(A3)
         SIGM = SLOS + SIGMS
         VMX = VM * COS(SLOS)
         VMY = VM * SIN(SLOS)
         XM  = RM * COS(SIGM)
         YM  = RM * SIN(SIGM)
************************************************************
  200    CONTINUE
*
************************************************************
*** MISSION RESULT ***  KILL = 0 ;  TGT  MISSED
**********************  KILL = 1 ;  TGT  DESTROYED
         XDIST = XT-XM
         YDIST = YT-YM
         DIST  = SQRT(XDIST**2 + YDIST**2)
         VC = SQRT((VTX-VMX)**2+(VTY-VMY)**2)
         TG = DIST/VC
         IF (DIST .LE.5)  KILL = 1
         IF (DIST .GT.5)  KILL = 0
         IF (XM .GT. (XT+30))CALL ENDJOB
*
SORT
************************************************************
******** OUTPUT AND PLOT CONTROL CARD **********************
************************************************************
SAMPLE
         CALL DRWG(1,1,XM,YM)
         CALL DRWG(1,2,XT,YT)
         CALL DRWG(2,1,TIME,DIST)
         CALL DRWG(3,1,TIME,CRE)
         CALL DRWG(4,1,TIME,CRED)
         CALL DRWG(5,1,CRE,CRED)
         CALL DRWG(6,1,TIME,F)
         CALL DRWG(7,1,TIME,U)
TERMINAL
         CALL ENDRW(NPLOT)
CONTRL FINTIM=5.9,DELT=0.001 ,DELS=0.003
PRINT   0.1,TG,XM,YM,XT,YT,CRE,CRED,DIST,KILL
END
STOP
```

APPENDIX F

PROGRAM OF THE BASIC COMMAND TO LOS WITH TWO-LEVEL RELAY

```
TITLE     BASIC COMMAND TO L.O.S
TITLE      WITH TWO LEVEL RELAY
TITLE     ***** YEUN, J.Y. *****
INTEG     RKSFX
INTGER    NPLOT,KILL
CONST     NPLOT=1,TCON=1.0
CONST     VM=500.,VT=250,PI=3.141593,KILL=0
INITIAL
          XT0 = 4000.
          YT0 = 1000.
          GAMT = PI
          F  = 0.
*
************************************************************
DERIVATIVE
************************************************************
NOSORT
*************************
*** TARGET PARAMETERS ***
*************************
          VTX = VT*COS(GAMT)
          VTY = VT*SIN(GAMT)
          XT = VTX*TIME + XT0
          YT = VTY*TIME + YT0
          SIGT = ATAN2(YT,XT)
          IF (TIME.GE.TCON) GO TO 50
*************************
*** MISSLE PARAMETERS ***
*************************
* PROGRAMMED GUIDANCE **************************************
*
          SIGM = SIGT+0.1
          VXM = VM * COS(SIGM)
          VYM = VM * SIN(SIGM)
          XM  = INTGRL(0.,VXM)
          YM  = INTGRL(0.,VYM)
          RM  = SQRT(XM**2 + YM**2)
          SIGMT = SIGM - SIGT
          CRE = RM * SIN(SIGMT)
          CRED = DERIV(0.,CRE)
          GO TO 200
*****************************
* ON-OFF GUIDANCE (BANG-BANG CONTROL)  *********************
*****************************
*
   50     CONTINUE
*

          G = 150.
          ACRE = ABS(CRE)
          ACRED = ABS(CRED)
          IF((ACRE+ACRED) .LT. 1.) G = 15
          F = CRE + (CRED*ACRED)/(2*G)
          U = -G * SIGN(1.,F)
          CRED = INTGRL(0.0,U)
          CRE = INTGRL(CRE,CRED)
*
          RM  = VM*TIME
          A3  = CRE/RM
```

```
         SIGMT = ARSIN(A3)
         SIGM = SIGT + SIGMT
         XM  = RM * COS(SIGM)
         YM  = RM * SIN(SIGM)
*************************************************************
  200    CONTINUE
*
*************************************************************
*** MISSION RESULT ***   KILL = 0 ;  TGT  MISSED
**********************   KILL = 1 ;  TGT  DESTROYED
         XDIST = XT-XM
         YDIST = YT-YM
         DIST  = SQRT(XDIST**2 + YDIST**2)
         IF (DIST .LE.5)  KILL = 1
         IF (DIST .GT.5)  KILL = 0
         IF (XM .GT. (XT+30))CALL ENDJOB
*
SORT
*************************************************************
******** OUTPUT AND PLOT CONTROL CARD ***********************
*************************************************************
SAMPLE
         CALL DRWG(1,1,XM,YM)
         CALL DRWG(1,2,XT,YT)
         CALL DRWG(2,1,TIME,DIST)
         CALL DRWG(3,1,TIME,CRE)
         CALL DRWG(4,1,TIME,CRED)
         CALL DRWG(5,1,CRE,CRED)
         CALL DRWG(6,1,TIME,F)
         CALL DRWG(7,1,TIME,U)
TERMINAL
         CALL ENDRW(NPLOT)
CONTRL FINTIM=5.9,DELT=0.001,DELS=0.003
PRINT   0.005,XM,YM,XT,YT,CRE,CRED,DIST,KILL
END
STOP
```

APPENDIX G

PROGRAM OF THE MANEUVERING TARGET WITH TWO-LEVEL RELAY

```
TITLE    BASIC COMMAND TO LOS
TITLE    WITH MANEUVERING TGT
TITLE    ***  YEUN, J.Y.   ***
INTEG    RKSFX
INTGER   NPLOT,KILL
CONST    NPLOT=1,TCON=1.0
CONST    VM=500.,VT=250,PI=3.141593,KILL=0
INITIAL
         XTO = 4000.
         YTO = 1000.
         GAMT = PI
         F  = 0.
*
************************************************************
DERIVATIVE
************************************************************
NOSORT
*************************
*** TARGET PARAMETERS ***
*************************
         VTX = VT*COS(GAMT)
         VTY = VT*SIN(GAMT)
         XT = VTX*TIME + XTO
         YT = 100*SIN(0.5*PI*TIME)+YTO
         SIGT = ATAN2(YT,XT)
         IF (TIME.GE.TCON)  GO TO 50
*************************
*** MISSLE PARAMETERS ***
*************************
* PROGRAMMED GUIDANCE **************************************
*
         SIGM = SIGT+0.1
         VXM = VM * COS(SIGM)
         VYM = VM * SIN(SIGM)
         XM  = INTGRL(0.,VXM)
         YM  = INTGRL(0.,VYM)
         RM  = SQRT(XM**2 + YM**2)
         SIGMT = SIGM - SIGT
         CRE = RM * SIN(SIGMT)
         CRED = DERIV(0.,CRE)
         GO TO 200
*****************************
* ON-OFF GUIDANCE (BANG-BANG CONTROL) *********************
*****************************
*
   50    CONTINUE
*
         G = 150.
         ACRE = ABS(CRE)
         ACRED = ABS(CRED)
         IF((ACRE+ACRED) .LT. 1.) G = 15.
         F = CRE + (CRED*ACRED)/(2*G)
         U = -G * SIGN(1.,F)
         CRED = INTGRL(0.0,U)
         CRE = INTGRL(CRE,CRED)
         ACRE = ABS(CRE)
*
         RM  = VM*TIME
         A3  = CRE/RM
```

```
         SIGMT = ARSIN(A3)
         SIGM =  SIGT + SIGMT
         XM  = RM * COS(SIGM)
         YM  = RM * SIN(SIGM)
************************************************************
  200    CONTINUE
*
************************************************************
*** MISSION RESULT ***  KILL = 0 ;  TGT  MISSED
**********************  KILL = 1 ;  TGT  DESTROYED
         XDIST = XT-XM
         YDIST = YT-YM
         DIST  = SQRT(XDIST**2 + YDIST**2)
         IF (DIST .LE.5)  KILL = 1
         IF (DIST .GT.5)  KILL = 0
         IF (XM .GT. (XT+30))CALL ENDJOB
*
SORT
************************************************************
******** OUTPUT AND PLOT CONTROL CARD **********************
************************************************************
SAMPLE
         CALL DRWG(1,1,XM,YM)
         CALL DRWG(1,2,XT,YT)
         CALL DRWG(2,1,TIME,DIST)
         CALL DRWG(3,1,TIME,CRE)
         CALL DRWG(4,1,TIME,CRED)
         CALL DRWG(5,1,CRE,CRED)
         CALL DRWG(6,1,TIME,F)
         CALL DRWG(7,1,TIME,U)
TERMINAL
         CALL ENDRW(NPLOT)
CONTRL FINTIM=5.9,DELT=0.001,DELS=0.003
PRINT   0.005,XM,YM,XT,YT,CRE,CRED,DIST,KILL
END
STOP
```

APPENDIX B

PROGRAM OF THE COMMAND TO PSEUDO-LOS WITH TWO-LEVEL RELAY

```
TITLE      PSEUDO - LOS COMMAND
TITLE      WITH TWO-LEVEL RELAY
TITLE     ***** YEUN, J.Y. *****
INTEG     RKSFX
INTGER    NPLOT,KILL
CONST     NPLOT=1,TCON=1.0
CONST     VM=500.,VT=250,PI=3.141593,KILL=0
INITIAL
          XT0 = 4000.
          YT0 = 1000.
          TG = 0.
          GAMT = PI
          F  = 0.
*
*************************************************************
DERIVATIVE
*************************************************************
NOSORT
**************************
*** TARGET PARAMETERS ***
**************************
          VTX = VT*COS(GAMT)
          VTY = VT*SIN(GAMT)
          XT = VTX*TIME + XT0
          YT = VTY*TIME + YT0
          SIGT = ATAN2(YT,XT)
          XLOS = XT + VTX*TG
          YLOS = YT + VTY*TG
          SLOS = ATAN2(YLOS,XLOS)
          IF (TIME.GE.TCON) GO TO 50
**************************
*** MISSLE PARAMETERS ***
**************************
* PROGRAMMED GUIDANCE ***************************************
*
          SIGM = SLOS + 0.1
          VMX = VM * COS(SIGM)
          VMY = VM * SIN(SIGM)
          XM  = INTGRL(0.,VMX)
          YM  = INTGRL(0.,VMY)
          RM  = SQRT(XM**2 + YM**2)
          SIGMS = SIGM - SLOS
          CRE = RM * SIN(SIGMS)
          CRED = DERIV(0.,CRE)
          GO TO 200
******************************
* ON-OFF GUIDANCE (BANG-BANG CONTROL) **********************
******************************
*
   50     CONTINUE
*
          G = 150.
          ACRE = ABS(CRE)
          ACRED = ABS(CRED)
          IF((ACRE+ACRED) .LT. 1.) G = 15.
          F = CRE + (CRED*ACRED)/(2*G)
          U = -G * SIGN(1.,F)
          CRED = INTGRL(0.0,U)
          CRE = INTGRL(CRE,CRED)
```

```
*
         RM  = VM*TIME
         A3  = CRE/RM
         SIGMS = ARSIN(A3)
         SIGM = SLOS + SIGMS
         VMX = VM * COS(SLOS)
         VMY = VM * SIN(SLOS)
         XM  = RM * COS(SIGM)
         YM  = RM * SIN(SIGM)
************************************************************
  200    CONTINUE
*
************************************************************
*** MISSION RESULT ***  KILL = 0 ;  TGT  MISSED
**********************  KILL = 1 ;  TGT  DESTROYED
         XDIST = XT-XM
         YDIST = YT-YM
         DIST  = SQRT(XDIST**2 + YDIST**2)
         VC = SQRT((VTX-VMX)**2+(VTY-VMY)**2)
         TG = DIST/VC
         IF (DIST .LE.5)  KILL = 1
         IF (DIST .GT.5)  KILL = 0
         IF (XM .GT. (XT+30))CALL ENDJOB
*
SORT
************************************************************
******** OUTPUT AND PLOT CONTROL CARD **********************
************************************************************
SAMPLE
         CALL DRWG(1,1,XM,YM)
         CALL DRWG(1,2,XT,YT)
         CALL DRWG(2,1,TIME,DIST)
         CALL DRWG(3,1,TIME,CRE)
         CALL DRWG(4,1,TIME,CRED)
         CALL DRWG(5,1,CRE,CRED)
         CALL DRWG(6,1,TIME,F)
         CALL DRWG(7,1,TIME,U)
TERMINAL
         CALL ENDRW(NPLOT)
CONTRL FINTIM=5.7,DELT=0.001 ,DELS=0.003
PRINT   0.1,TG,XM,YM,XT,YT,CRE,CRED,DIST,KILL
END
STOP
```

APPENDIX I

PROGRAM OF THE BASIC COMMAND TO LOS WITH SATURATION CONTROL

```
TITLE    BASIC COMMAND TO L.O.S
TITLE      MISSLE  CONTROL
TITLE    WITH SATURATION CONTROL
INTEG    RKSFX
INTGER   NPLOT,KILL,CUR
CONST    NPLOT=1,TCON=1.0,CUR=1
CONST    VM=500.,VT=250,PI=3.141593,KILL=0
PARAM    M = 10.
INITIAL
         XT0 = 4000.
         YT0 = 1000.
         GAMT = PI
         F  = 0.
*
************************************************************
DERIVATIVE
************************************************************
NOSORT
*************************
*** TARGET PARAMETERS ***
*************************
         VTX = VT*COS(GAMT)
         VTY = VT*SIN(GAMT)
         XT = VTX*TIME + XT0
         YT = VTY*TIME + YT0
         SIGT = ATAN2(YT,XT)
         IF (TIME.GE.TCON) GO TO 50
*************************
*** MISSLE PARAMETERS ***
*************************
* PROGRAMMED GUIDANCE **************************************
*
         SIGM = SIGT+0.1
         VXM = VM * COS(SIGM)
         VYM = VM * SIN(SIGM)
         XM  = INTGRL(0.,VXM)
         YM  = INTGRL(0.,VYM)
         RM  = SQRT(XM**2 + YM**2)
         SIGMT = SIGM - SIGT
         CRE = RM * SIN(SIGMT)
         CRED = DERIV(0.,CRE)
         GO TO 200
*****************************
* ON-OFF GUIDANCE (BANG-BANG CONTROL) *********************
*****************************
*
   50    CONTINUE
*
         G = 150.
         ACRED = ABS(CRED)
         F = CRE + (CRED*ACRED)/(2*G)
         U = -G * SIGN(1.,F)
         IF (ABS(F) .LT. M) U= -G*F/M
         CRED = INTGRL(0.0,U)
         CRE = INTGRL(CRE,CRED)
*
         RM  = VM*TIME
         A3  = CRE/RM
         SIGMT = ARSIN(A3)
```

```
         SIGM = SIGT + SIGMT
         XM   = RM * COS(SIGM)
         YM   = RM * SIN(SIGM)
**********************************************************
  200    CONTINUE
*
**********************************************************
*** MISSION RESULT ***  KILL = 0 ;  TGT  MISSED
**********************  KILL = 1 ;  TGT  DESTROYED
         XDIST = XT-XM
         YDIST = YT-YM
         DIST  = SQRT(XDIST**2 + YDIST**2)
         IF (DIST .LE.5)  KILL = 1
         IF (DIST .GT.5)  KILL = 0
*
SORT
**********************************************************
******** OUTPUT AND PLOT CONTROL CARD *********************
**********************************************************
SAMPLE
         CALL DRWG(1,CUR,XM,YM)
         CALL DRWG(2,CUR,TIME,DIST)
         CALL DRWG(3,CUR,TIME,CRE)
         CALL DRWG(4,CUR,CRE,CRED)
         CALL DRWG(5,CUR,TIME,F)
         CALL DRWG(6,CUR,TIME,U)
TERMINAL
         IF (CUR .EQ. 3) CALL ENDRW(NPLOT)
         CUR = CUR + 1
CONTRL FINTIM=5.65,DELT=0.001,DELS=0.003
PRINT   0.005,XM,YM,XT,YT,CRE,CRED,DIST,KILL
END
PARAM   M = 5.
END
PARAM   M = 1.
END
STOP
```

APPENDIX J

PROGRAM OF THE MANEUVERING TARGET WITH SATURATION CONTROL

```
TITLE    BASIC COMMAND TO LOS
TITLE      (MANEUVERING TGT)
TITLE    WITH SATURATION CONTROL
INTEG    RKSFX
INTGER   NPLOT,KILL,CUR
CONST    NPLOT=1,TCON=1.0,CUR=1
CONST    VM=500.,VT=250,PI=3.141593,KILL=0
PARAM    M = 10.
INITIAL
         XTO = 4000.
         YTO = 1000.
         GAMT = PI
         F  = 0.
*
**************************************************************
DERIVATIVE
**************************************************************
NOSORT
**************************
*** TARGET PARAMETERS ***
**************************
         VTX = VT*COS(GAMT)
         VTY = VT*SIN(GAMT)
         XT = VTX*TIME + XTO
         YT = 100*SIN(0.5*PI*TIME)+YTO
         SIGT = ATAN2(YT,XT)
         IF (TIME.GE.TCON)  GO TO 50
**************************
*** MISSILE PARAMETERS ***
**************************
* PROGRAMMED GUIDANCE ****************************************
*
         SIGM = SIGT+0.1
         VXM = VM * COS(SIGM)
         VYM = VM * SIN(SIGM)
         XM  = INTGRL(0.,VXM)
         YM  = INTGRL(0.,VYM)
         RM  = SQRT(XM**2 + YM**2)
         SIGMT = SIGM - SIGT
         CRE = RM * SIN(SIGMT)
         CRED = DERIV(0.,CRE)
         GO TO 200
******************************
* ON-OFF GUIDANCE (BANG-BANG CONTROL) **********************
******************************
*
   50    CONTINUE
*
         G = 150.
         ACRED = ABS(CRED)
         F = CRE + (CRED*ACRED)/(2*G)
         U = -G * SIGN(1.,F)
         IF (ABS(F).LT.M) U=-G*F/M
         CRED = INTGRL(0.0,U)
         CRE = INTGRL(CRE,CRED)
         ACRE = ABS(CRE)
*
         RM  = VM*TIME
         A3  = CRE/RM
```

```
         SIGMT = ARSIN(A3)
         SIGM = SIGT + SIGMT
         XM  = RM * COS(SIGM)
         YM  = RM * SIN(SIGM)
************************************************************
  200    CONTINUE
*
************************************************************
*** MISSION RESULT ***  KILL = 0 ;  TGT  MISSED
**********************  KILL = 1 ;  TGT  DESTROYED
         XDIST = XT-XM
         YDIST = YT-YM
         DIST  = SQRT(XDIST**2 + YDIST**2)
         IF (DIST .LE.5)  KILL = 1
         IF (DIST .GT.5)  KILL = 0
*
SORT
************************************************************
******** OUTPUT AND PLOT CONTROL CARD **********************
************************************************************
SAMPLE
         CALL DRWG(1,CUR,XM,YM)
         CALL DRWG(2,CUR,TIME,DIST)
         CALL DRWG(3,CUR,TIME,CRE)
         CALL DRWG(4,CUR,CRE,CRED)
         CALL DRWG(5,CUR,TIME,F)
         CALL DRWG(6,CUR,TIME,U)
TERMINAL
         IF (CUR .EQ.3) CALL ENDRW(NPLOT)
         CUR = CUR + 1
CONTRL FINTIM=5.65,DELT=0.001,DELS=0.003
PRINT   0.005,XM,YM,XT,YT,CRE,CRED,DIST,KILL
END
PARAM  M = 5.
END
PARAM  M = 1.
END
STOP
```

APPENDIX K

PROGRAM OF THE COMMAND TO PSEUDO-LOS WITH SATURATION CONTROL

```
TITLE    PSEUDO - LOS COMMAND
TITLE    WITH  SATURATION CONTROL
TITLE    ***** YEUN, J.Y. *****
INTEG    RKSFX
INTGER   NPLOT,KILL,CUR
CONST    NPLOT=1,TCON=1.0,CUR=1
CONST    VM=500.,VT=250,PI=3.141593,KILL=0
PARAM    M = 10.
INITIAL
         XT0 = 4000.
         YT0 = 1000.
         TG = 0.
         GAMT = PI
         F  = 0.
*
************************************************************
DERIVATIVE
************************************************************
NOSORT
*************************
*** TARGET PARAMETERS ***
*************************
         VTX = VT*COS(GAMT)
         VTY = VT*SIN(GAMT)
         XT = VTX*TIME + XT0
         YT = VTY*TIME + YT0
         SIGT = ATAN2(YT,XT)
         XLOS = XT + VTX*TG
         YLOS = YT + VTY*TG
         SLOS = ATAN2(YLOS,XLOS)
         IF (TIME.GE.TCON) GO TO 50
*************************
*** MISSLE PARAMETERS ***
*************************
* PROGRAMMED GUIDANCE **************************************
*
         SIGM = SLOS + 0.1
         VMX = VM * COS(SIGM)
         VMY = VM * SIN(SIGM)
         XM  = INTGRL(0.,VMX)
         YM  = INTGRL(0.,VMY)
         RM  = SQRT(XM**2 + YM**2)
         SIGMS = SIGM - SLOS
         CRE = RM * SIN(SIGMS)
         CRED = DERIV(0.,CRE)
         GO TO 200
******************************
* ON-OFF GUIDANCE (BANG-BANG CONTROL) *********************
******************************
*
  50     CONTINUE
*
         G = 150.
         ACRED = ABS(CRED)
         F = CRE + (CRED*ACRED)/(2*G)
         U = -G * SIGN(1.,F)
         IF (ABS(F) .LT.M) U = -G * F /M
         CRED = INTGRL(0.0,U)
         CRE = INTGRL(CRE,CRED)
```

```
*
         RM  = VM*TIME
         A3  = CRE/RM
         SIGMS = ARSIN(A3)
         SIGM = SLOS + SIGMS
         VMX = VM * COS(SLOS)
         VMY = VM * SIN(SLOS)
         XM  = RM * COS(SIGM)
         YM  = RM * SIN(SIGM)
***********************************************************
  200    CONTINUE
*
***********************************************************
*** MISSION RESULT ***  KILL = 0 ;  TGT  MISSED
**********************  KILL = 1 ;  TGT  DESTROYED
         XDIST = XT-XM
         YDIST = YT-YM
         DIST  = SQRT(XDIST**2 + YDIST**2)
         VC = SQRT((VTX-VMX)**2+(VTY-VMY)**2)
         TG = DIST/VC
         IF (DIST .LE.5)  KILL = 1
         IF (DIST .GT.5)  KILL = 0
*
SORT
***********************************************************
******** OUTPUT AND PLOT CONTROL CARD *********************
***********************************************************
SAMPLE
         CALL DRWG(1,CUR,XM,YM)
         CALL DRWG(2,CUR,TIME,DIST)
         CALL DRWG(3,CUR,TIME,CRE)
         CALL DRWG(4,CUR,CRE,CRED)
         CALL DRWG(5,CUR,TIME,F)
         CALL DRWG(6,CUR,TIME,U)
TERMINAL
         IF (CUR .EQ.3) CALL ENDRW(NPLOT)
         CUR = CUR + 1
CONTRL FINTIM=5.65,DELT=0.001 ,DELS=0.003
PRINT   0.005,TG,XM,YM,XT,YT,CRE,CRED,DIST,KILL
END
PARAM   M = 5.
END
PARAM   M = 1.
END
STOP
```

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